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Insituform and Other Sewer Rehabilitation Techniques

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INSITUFORM AND OTHER SEWER REHABILITATION TECHNIQUES

by

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Cooperative Agreement No. CR806625

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in cooperation with
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16. ABSTRACT

In 1979 the City of Hagerstown, Maryland embarked upon a very aggressive sanitary sewer collection system rehabilitation program utilizing sewer lining by the "Insituform" method, testing and sealing of joints and manholes with chemical grout, and the point repair of sewer mains. A review has been made of results. In addition, the author or his representative reviewed a site in LaGrange Highlands, Illinois, where sliplining with a conventional polyethylene liner was being performed, and thirteen "Insituform" sites. The study compares these repair options. For the "Insituform" process discussion includes installation procedures and problems, the product limitations, spatial requirements of the equipment, and safety hazards and procedures.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activites and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges, establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Infiltration of stormwater into sanitary sewers through defects in the sewer lines can add substantially to the volume of wastewater reaching a sewage treatment plant and requiring treatment during wet weather. One method for rehabilitating sewer lines to reduce infiltration is a sewer lining technique called "Insituform." This report describes experience with the use of this lining method at Hagerstown, Maryland.

Francis T. Mayo, Director
Water Engineering Research Laboratory

PREFACE

In recent years the Environmental Protection Agency, in its quest to clean up the surface and ground waters of this nation, has placed increased emphasis upon the performance optimization of existing wastewater treatment equipment by the reduction of the hydraulic loadings imposed upon this equipment. Much attention is now being directed toward developing cost effective means of controlling the flows seen at treatment facilities by the reduction or elimination of extraneous clear water from within the sanitary sewer collection system. Past sewer rehabilitation projects, however, have been relatively unsuccessful in permanently eliminating infiltration contributions from the sewers for several obvious reasons: (1) some present rehabilitation techniques seem temporary in nature, while (2) others simply force infiltration waters to migrate to a point of system weakness where they may enter the system. The E.P.A. has shown interest in the "Insituform" method of lining deteriorated conduits because it is quite effective in eliminating infiltration in sewer mains, while at the same time supplementing the structural and hydraulic properties of the conduit; also since excavation is not generally required in this process, only minimal surface disruption and restoration is necessary.

The "Insituform" concept was developed in Great Britain in 1971, and used chiefly in Europe and Australia until its introduction into North America in 1977. Because of the rather short history of the product in this nation, only very limited data was available with which to establish standards of construction; without these standards, potential users in the past were unable to precisely define the end product desired or to determine the effectiveness of the technique.

The primary objective of this study is to compare the "Insituform" sewer lining technique with other widely-used methods of sewer rehabilitation in areas of differing geology, as well as to establish a track record on this continent for the product; this comparison includes, but is not limited to, parameters such as the relative effectiveness of each alternative, the economics of the different techniques, the social and environmental impact of different methods, as well as the limitations and difficulties associated with various alternatives.

Thirteen (13) sites at which "Insituform" was in place were visited in the United States and Canada in order to ascertain the durability of the product; at each location, interviews with participating municipal officials and engineers were conducted, and before-and-after video tapes of rehabilitated sections viewed.

Additionally, in this report is included recommended procedures for the installation of "Insituform," as well as an evaluation of the possibilities of utilizing variations of the technique in the rehabilitation of house laterals without excavation. To obtain representative data for this analysis, all inspectors on the sewer rehabilitation project in Hagerstown, Maryland were given detailed checklists to fill out on each rehabilitation technique. Sophisticated flow monitoring equipment was installed upstream and downstream of selected test sections in order to document before-and-after properties of rehabilitation alternatives. Detailed interviews were conducted with municipal officials and employees, along with consulting engineers who took an active part in the project; before-and-after video tapes of rehabilitated section in Hagerstown were used where available.

Herein, then, is presented the study based upon the documentation and data gathered.

ABSTRACT

This research report has been prepared in an effort to compare the relative merits and limitations of the various sewer rehabilitation procedures, with specific attention being paid to the "Insituform" technique; the track record of this lining method since it introduction onto the North American continent was also reviewed, with particular attention being paid to the product duribility.

In 1979 the City of Hagerstown, Maryland embarked upon a very aggressive sanitary sewer collection system rehabilitation program utilizing sewer lining by the "Insituform" method, testing and sealing of joints and manholes with chemical grout, and the point repair of sewer mains using force account labor; additionally, the author or his representative reviewed a site in LaGrange Highlands, Illinois, where sliplining with a conventional polyethylene liner was being performed, as well as the thirteen above-referenced "Insituform" historical sites. The study compares these repair options, taking into consideration such factors as logistic problems, equipment and labor required by each, the environmental impact as related to noise, air and water pollution, the social impacts including public inconveniences due to traffic disruption, utility relocation, and the temporary disruption of sanitary service, economic parameters including adjusted cost comparisons and the cost effectiveness of each alternative, the effectiveness of the technique in reducing mainline infiltration, durability of the products, along with before-and-after flow properties of the rehabilitated sections; attention was paid to the effect that different geological conditions have upon various techniques. It should be noted that although the LaGrange Highlands project was a representative application of the conventional sliplining technique, it was of very small scale when compared to the Hagerstown lining work and as such, the comparisons drawn may be somewhat misleading; this possiblity should be borne in mind. The study will analyze such parameters of the "Insituform" process as installation procedures and problems, the product limitations, spatial requirements of the equipment, and safety hazards and procedures. An evaluation noting the possibility of implementing variations of the "Insituform" lining procedure in the rehabilitation of house laterals without excavation will be included.

The conclusions and recommendations forwarded in this text should assist potential clients, engineers and installers in determining the viability of the liner in definite situations, and in specifying or installing "Insituform" in various applications.

This analysis is submitted by Thomas I. Simmons and Associates, Consulting Engineers, in partial fulfillment of Cooperative Agreement No. CR806625 entered into by and between the United States Environmental Protection Agency and the City of Hagerstown, Maryland, and covers the period from November 11, 1979 through December 1983, with work on this portion to be completed in December 1983.

CONTENTS

Disclaimer ii
Foreword iii
Preface iv
Abstract vi
Figures x
Tables xi
Abbreviations and Symbols xii
Achnowledgement xiii
Technical Advisory Committee xiv

1. Introduction 1
2. Conclusion 4
   - Site Studies 4
   - Hagerstown Rehabilitation Study 6
3. Recommendations 9
   - Site Studies 9
   - Hagerstown Rehabilitation Study 9
4. The Study 11
   - Site Studies 11
   - Comparison of Rehabilitation Techniques. 11
     - Sewer Rehabilitation Requirement 11
     - Methodology. 13
       - Flowmetering 13
       - Test Section Selection 14
       - Questionnaires 15
       - Division of Responsibility 21
   - Alternatives 22
     - Procedures and Equipment 22
       - Equipment 25
       - Installation Procedure 27
     - Method Limitations 35
       - Weather 35
       - Section Length 37
       - Spatial Requirements 38
       - Flow Bypassing Requirements 40
       - On-Grade Entry 41
       - Root Procedures 41
       - Safety 42
       - Remote Plants 45
       - Time 46
       - Public Relations 48
       - Final Product Characteristics 49
       - Before and After Sewer Conditions 53
       - Cost Effective Analysis of "Insituform" and Other Rehabilitation Techniques in Different Geologies . . . 67
       - Service Limitation 72
       - "Insituform" Durability and Service Life 74

FIGURES

Number	Page
1. Inspectors Checklist Sewer Sealing	17
2. Inspectors Checklist Insituform Lining	18
3. Inspectors Checklist Sliplining	19
4. Inspectors Checklist Point Repairs	20

TABLES

Number		Page
1.	Test-and-Seal Repair Infiltrations	55
2.	Weir Analysis of Infiltration (LaGrange Highlands)	59
3.	Manning Roughness Coefficient	62
4.	Insituform Flowmetering Data	66
5.	Cost-Effectiveness of Rehabilitation Techniques Studied	68
6.	Cost-Effectiveness "Insituform" vs Sliplining	69

LIST OF ABBREVIATIONS AND SYMBOLS

G -- gallons
GPM -- gallons per minute
GPD -- gallons per day
MGD -- million gallons per day
m -- meters
cm -- centimeters
mm -- millimeters
km -- kilometers
l -- liters
M^3 -- cubic meters
M^3/Day -- cubic meters per day
ft. -- feet
in. -- inches
ft.^{3}(C.F.) -- cubic feet
min. -- minutes
sec. -- seconds
L.F. -- lineal feet
g -- grams
kg. -- kilograms
F -- Fahrenheit
C -- Centigrade

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SECTION 1

INTRODUCTION

There is widespread concern offered within the Public Works industry relative to the progressively deteriorating condition of sewer collection systems across the nation. Larger and larger wastewater treatment plants are being designed and constructed every day in many cases for purposes of treating flows, which by their origin, do not belong in the sanitary system; due to the lack of a cost effective means of rehabilitating the often times forgotten sanitary sewers, the extraneous clear water component of the hydraulic loading imposed upon sewers and treatment facilities will remain and in fact grow over time. In many instances engineers are hesitant to attack the I/I problem that exists within the collection system at its source due to the relative uncertainty of the results which might be anticipated from a sewer rehabilitation program. Basically it is much less risky to design an oversized treatment plant which can accomodate extraneous flows projected to be tributary to it than it is to attempt to control and limit these clear water flows; however the engineer is in fact doing a disservice to his client by overlooking some cost effective measures of eliminating extraneous flows in the network. Increased attention must be paid to the collection system by engineers, municipal employees, municipal officials and regulatory agencies. It is imperative that the citizenry be educated in the importance of a reliable and functional wastewater collection system. This study will attempt to present methods by which substandard conduits can be repaired, and will compare advantages and disadvantages of each alternative.

Previous studies on this product were performed to determine the feasibility and effectiveness of the "Insituform" liner in rehabilitating deteriorated sewers. As part of these earlier reports, installation procedures were reviewed, with flow characteristics and physical properties of the finished liner determined.

Exhaustive field studies performed basically in Hagerstown, Maryland; LaGrange Highlands, Illinois and some thirteen (13) North American sites supplemented with data gathered during the preparation of earlier reports on the "Insituform" process were utilized to compare and evaluate various sewer rehabilitation techniques, considering parameters such as the effectiveness and durability of the product in eliminating extraneous clear water from sewers, the procedures and problems associated with each rehabilitation option, the economic aspects of each option, and the sociological ramifications of each technique. Generally speaking, each rehabilitation alternative considered in this report has its place in the overall scheme of collection system renovation; hence, defective segments of sewers must be considered individually, using the inspection tools available, to establish the best rehabilitation application for each instance. Herein, factors to be considered in determining the merits of various rehabilitation alternatives for specific sites are noted.

One question that potential "Insituform" users ask is with respect to the effectiveness and durability of the product when exposed to a typical sewerage environment over an extended period of time. The conservative nature of consultants, municipalities, and private industry had to be addressed before "Insituform" would be considered a viable option for rehabilitating conduits. Prior to specifying "Insituform" as a sewer rehabilitation technique to be used in the Hagerstown project, the City of Hagerstown and its engineering consultant thoroughly investigated the process and learned that over 200,000 feet (60,960 m.) had been successfully installed throughout the United States. In an effort to respond to this typical skepticism, numerous sites were visited in which "Insituform" had been in the ground a considerable length of time. Questions were posed to officials responsible for each installation regarding the need for the "Insituform" construction procedures, problems associated with the work, the effectiveness of the liner, and the durability of the repair material over time; evaluations based upon these visits are presented in this text with appropriate conclusions made. This should enable prospective utilizers of this product to make an accurate judgement regarding the feasibility of its use in each circumstance.

Some attention will be paid to the problem of rehabilitating service laterals on private property without damaging the property. In order to achieve the removal of infiltration from a sewer collection system, defective services must be rehabilitated to the extent cost effectively possible. Ground water which through repair work is prevented from entering a mainline will seek out other avenues of entrance to the collection system, many times migrating to deterioratd service lines or manholes.

"Insituform" has several techniques in the developmental stages which may rehabilitate service laterals without the need for any excavation; the feasibility of this work will be discussed in this report.

The information presented in this report represents a joint effort by the United States Environmental Protection Agency, Water Engineering Research Laboratory Storm and Combined Sewer Section, Thomas I. Simmons and Associates, Consulting Engineers of Rochelle, Illinois, the City of Hagerstown, Maryland, Water Pollution Control staff, along with various contractors, municipalities, agencies and engineers involved in the sewer rehabilitation field.

SECTION 2

CONCLUSIONS

SITE STUDIES

The results of the site studies made, the interviews conducted, and the video tapes reviewed indicates that the "Insituform" method of sewer lining has been found to be a viable cost-effective alternative of rehabilitation in different applications for different reasons; each situation must be considered individually to determine the appropriateness of the technique."

Sewers have been lined by the "Insituform" method in vastly different locations and geologies, and under different climatic conditions--from Winnipeg, Canada in the middle of winter to central Florida in the summer; sewers transporting domestic strength waste from municipalities as well as high-strength chemical wastes in industrial situations have been lined with the product, and are holding up reasonably well under the conditions imposed upon the liner material.

The reasons for choosing the "Insituform" liner rather than other repair alternatives in the thirteen (13) sites visited also varied widely, but basically came down to the logistics of the site. Many industrial plants chose lining by "Insituform" for sewers running under buildings, where the initial construction cost was not only below that for other options but where the no-excavation procedure provided for minimal disruption of production during construction. In many instances where lining was necessary to renovate a conduit, "Insituform" was selected rather than conventional lining means; where restoration costs associated with measures requiring excavation are considerable or prohibitive, in built-up areas, areas with numerous services or with land of great value, "Insituform" was found to be the most economical method of sewer rehabilitation. In some areas, legal problems of gaining access to a site necessitated the use of "Insituform because of its non-destructive and non-disruptive nature.

Since lining by "Insituform" takes much less time than does conventional sliplining, situations in which lengthy periods of construction cannot be tolerated lend themselves to solution via the inversion process. Sites where project staging areas are limited or traffic control might cause problems favor "Insituform," since it requires less equipment space and can easily be adapted to the remote location of installation and curing equipment.

Generally, in the applications studied for that phase of this report, the lining was implemented to eliminate either infiltration or exfiltration from sewer stretches, or to provide structural integrity to defective or severely deteriorated pipes. The parties interviewed generally agreed that the product was effective in the performance of this designated task, and that they would consider utilizing this technique again.

In some projects a degree of structural reinforcement was required to add life to badly-deteriorated sewers. Although the sites studied had a relatively short history of performance, inspections revealed that the conduit cross-sections had not changed appreciably over the liner life; in three cases where weak spots and bubbles were detected in the post-rehabilitation television inspection prior to client acceptance, the lining was either removed and the section relined to acceptance, or a point repair was made. Bubbles or weak spots were documented in Winnepeg, Michigan and Hagerstown.

Additionally the liners observed showed no noticeable changes in physical properties as a result of normal useage and maintenance factors. Trouble spots noted in liners generally were caused during the actual lining operations; once the resin was cured, the structure remained basically unaltered by time and nature.

Part of this study then is limited to an analysis of some thirteen (13) "Insituform" sites across the North American continent, concerning itself mainly with the reasons behind its utilization, installation procedures, product effectiveness and product durability.

HAGERSTOWN REHABILITATION STUDY

As is the case with most new products, the marketing claims of "Insituform" are very impressive; this study has attempted to assemble a preponderance of field data to either validate or invalidate these assertions, and in doing so to ascertain the cost effectiveness of the product along with its durability and installation techniques. The major conclusions derived from this survey are listed below:

1. With all mainline sewer rehabilitation techniques studied, the effectiveness of each in eliminating cost-effective infiltration from the sanitary collection system is directly dependent upon the rehabilitation of appurtenant facilities such as manholes, service laterals, etc.

2. The sanitary sewer rehabilitation program within any municipality must be an ongoing maintenance activity. Rehabilitated sewers, lift stations, manholes, etc. begin to deteriorate as soon as the repair is complete; this is evidenced by the gradual increase in wet weather flows seen at the treatment plant following completion of a collection system rehabilitation project.

3. Before-and-after flow data collected in this study revealed test-and-seal, point repair, conventional sliplining, and "Insituform" lining all to be successful in reducing the mainline infiltration of ground waters.

4. The durability of each technique over the three year period of the study was very good. Specifically important was the apparent lack of deterioration of the point repair/seal rehabilitation alternative after two to three years in place. Recent discussions with the City of Hagerstown staff have indicated that a number of sections which received test-and-seal repairs were dIsplaying a return of infiltrating ground water, however; plans are now in preparation to line these stretches with "Insituform". During the course of the collection system project, it was determined that some manhole sections in which grouting was planned could not be successfully sealed, due to large voids or incompatible material in the sewer backfill; these sections were analyzed for cost-effectiveness and then lined with "Insituform". Much grouting performed in previous programs within Hagerstown had, according to City staff, deteriorated to the point

of ineffectiveness. In many instances these lines were successfully rehabilitated using "Insituform" in the recent program.

5. In some study sections lined with "Insituform" flow data indicated the technique to be relatively ineffective in reducing infiltration; this could have been due to any of the following causes:

   a. Ground water may have been eliminated from entering the collection system mains, but migrated to deteriorated system elements such as services or manholes where it eventually infiltrated.

   b. Tolerances associated with flow measuring equipment and methods may have provided data which might not be totally representative. Numerous inconsistencies in the flow metering data shown in Table 4 give a strong indication that this item may very likely be the major contributing factor.

Overall, when considering all data presented, and recent deterioration of grouting sections (not evidenced by flow data, but determined by City to be present) "Insituform" could be considered quite effective in eliminating the infiltration of ground water from mainline sewers.

6. Although the "Insituform" manufacturer contends that the smoothness of the liner combined with the very thin liner cross-sectional thickness provides a repair with a hydraulic capacity greater than that which originally was present, this was not borne out in every test section. These variations were primarily due to the following factors:

   a. The calculated Manning roughness coefficient (n) was higher in the field than that declared by the manufacturer.

   b. The accuracy of the equipment used (1/8") may contribute inherent inaccuracies to the calculations; however, it is thought that these variation would compensate over test sections considered.

7. The "Insituform" method of reinstating services without excavation is an excellent concept, however a concentrated development effort with respect to the

"Insitucutter" is apparently necessary to render the system reliable in small-bore and large-bore sewers. Problems in positioning the drill in 8-inch and smaller bore sewers have been documented in the Northbrook E.P.A. Study, where a number of previously-televised severely protruding taps, significant offset joints, badly broken pipe, etc. had to be dug up and repaired when the "Insitucutter" could not negotiate the defects; conversations with WSSC also indicated this to be the case. Further study and development of this instrument should be considered.

8. Methods of lining service laterals without excavation are currently being developed by various lining firms, with some of the techniques appearing quite feasible; much additional study and development work is necessary to perfect this repair method.

9. Each repair technique has its advantages and problems; individual applications should be considered, weighing costs versus benefits for each alternative at each site.

10. Initial construction cost figures indicate the most cost-effective method of sewer system rehabilitation studied herein to be the point repair/test-and-seal combination, followed in order by conventional sliplining and "Insituform". These rankings may change when the life and serviceability of each alternative is considered, especially considering apparent problems the City staff has noted in test-and-seal work. Additionally, it should be noted that the conventional lining project study was very small in comparison with the Hagerstown "Insituform" work, with limited service reinstatement and surface restoration; in built-up areas with access problems high restoration costs and numerous service connections "Insituform" would most likely be more economical than conventional lining. Each application must be analyzed individually.

SECTION 3

RECOMMENDATIONS

SITE STUDIES

A certain amount of follow-up study should be pursued in this case, in an effort to establish the long-term effects that a potentially destructive environment would have on "Insituform." Essentially the sites visited in this report had been lined within the past five year and might not be good examples of the far-reaching results of continued exposure to wastewater; possibly some early "Insituform" installations in Europe might be studied.

Consideration should be given to keeping abrest of the ongoing technical advances associated with this product. Research is currently being performed on an advanced internal service-cutting system as well as the development of a technique for the lining of service laterals without excavation. As most individuals and firms involved with the art of sewer rehabilitation will attest, the elimination of extraneous clear water flows from the sanitary sewer system will not be approached until an acceptable cost-effective means of rehabilitating sewer laterals is developed and refined.

The "Insituform" procedure is an advancement in the field of sewer rehabilitation, and, as such, deserves a great deal of attention in the future.

Insufficient quality control was evidenced in three of these early installations, both in installation techniques and materials. "Insituform" in liner arrived at the site too long or too short, or with skin or seam imperfections that resulted in installation problems. Lack of preparation or attention to detail in the inversion and curing phases contributed to problems in the field; preventative equipment maintenance should also receive a higher priority. It should be remembered that these problems occured when the process was in its infancy on the continent.

HAGERSTOWN REHABILITATION STUDY

"Insituform" installers should pay careful attention to safety problems associated with their technique. The use of hot water under pressure in supplying the resin curing media for this process deserves specific concern; coupled with height at which the water is drawn from and discharged into the inversion tube, a very dangerous construction situation exists, especially during curing. Normal safety precautions with respect to construction scaffolding and work in enclosed areas should be exercised also.

The manufacturer should work to develop a reliable means of internally re-instating services in all sizes of sewers strictly by mechanical means; the "Insitucutter" should be modified with this end in mind.

A final recommendation is that the United States Environmental Protection Agency sponsor a detailed technical study to establish the feasibility of rehabilitating sewer laterals without excavating in a cost-effective manner.

SECTION 4

THE STUDY

SITE STUDIES

This portion of the total study was performed under Cooperative Agreement CR806625 and essentially consisted of three separate phases at each of the thirteen (13) scattered sites:

Phase 1 - Conduct an in-depth interview with personnel closely involved with the initial sewer relining project, addressing the reasoning behind the method selected, construction procedures and problems, cost of the installation, effectiveness of the liner in eliminating extraneous flows, and any perceptible deterioration of the liner over time.

Phase 2 - Perform an on-site investigation of the rehabilitated section, noting specific terrain features as well as current liner conditions.

Phase 3 - Obtain and review pre-Insituform video tapes, if available, as well as post-Insituform tapes and establish any notable differences which have come about, giving reasons for these differences.

Data gathered through these means is herein assembled and interpreted, and presented in such a manner which might act to educate any party interested in the possible application of this advanced technology.

COMPARISON OF REHABITATION TECHNIQUES

SEWER REHABILITATION REQUIREMENT

The City of Hagerstown, Maryland, through its Consulting Engineer, completed a comprehensive Sewer System Evaluation Survey of the municipal collection system in 1976. The function of such an analysis is to establish the most cost-effective means of dealing with clear water flows for which the separate sanitary system was not designed; whether it be to eliminate the extaneous flows from the sewers or to transport and treat them at the wastewater plant. Basically the conclusions presented in this SSES report are listed below:[1]

1. The City of Hagerstown sewer system had an estimated 5.0 MGD of excessive infiltration and an estimated 6.4 MGD of excessive inflow.

2. It was cost-effective to correct defective elements of the system in order to remove excessive infiltration. It was estimated to cost about $800,000 to correct the sources of excessive infiltration as compared with about $3,235,000 to treat the additional 5.0 MGD of excessive infiltration.

3. The critical sewer sections contributing the excessive infiltration were located in the following sewer lines:

   Northern Avenue - (M.H. 1-3 through M.H. 1-7)

   Memorial Boulevard - (M.H. 16-11 through M.H. 9-6)

   Hamilton Run Interceptor - (M.H. 6-12 through M.H. 6-13)

   Wabash Avenue - (M.H. 16-11 through M.H. 16-13)

4. Excessive infiltration through the walls of manhole was found in one basin where 32 precast manholes leaked.

5. Excessive inflow entered the sewer system mainly through illegal area drains and roof leaders.

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[1] Sewer System Evaluation Survey, City of Hagerstown, Washington County, Maryland, Buchart-Horn, Consulting Engineers, York, PA, 1976, P.I-1

6. It was estimated to be cost-effective to correct the excessive inflow; the anticipated cost was about $29,300 to correct the sources of excessive inflow.

In this phase of the current study, the emphasis will be placed upon the cost-effective collection system rehabilitation techniques which were used to relieve the main lines in Hagerstown of excessive infiltration; namely the Testing-and-Sealing of joints, Point Repair work, and Pipe Lining. Control of inflow sources is outside the scope of this report.

METHODOLOGY

This phase of the study was executed fundamentally on two levels: (1) a quantitative study of each rehabilitation technique mentioned above considering effectiveness, properties, and costs with detailed comparison judgements made on each alternative; and (2) qualitative attention paid to each alternative in order to establish procedures and limitations of the product as well as its viability in different applications.

Flowmetering

Prior to the selection of test sites by the municipality and the consultant, it was imperative to choose an accurate means by which to meter flows in the test sections prior to and after rehabilitation; meaningful data must be representative of flows under vastly varying conditions.

An automatic flow monitoring and recording system developed by American Digital Systems, Incorporated, of Huntsville, Alabama was used in Hagerstown for this study. In this system, the conduit flow is measured in the pipe upstream of a manhole, rather than within the manhole where erroneous data may result from turbulence, accelerating flows, drawdown, etc. A pressure transducer bolted to a metal ring of adjustable diameter is placed far up in the incoming pipe; this ring is expanded into place. The transducer is a pressure sensor that transforms the depth of flow into an electric voltage signal in increments of 1/8 inch (3 mm). This signal is stored in a memory bank; a timer unit which is adjustable from 5 to 15 minutes sets the sampling interval at a frequency capable of measuring relatively rapid variations in flow. An accurate depth-to-discharge relationship must be developed for each site studied. The method employed for the Hagerstown flowmetering utilizes the Manning Equation for open channel flow to formulate this relationship, where:

$$Q = \frac{1.486}{n} A R_h^{2/3} S^{1/2}$$

in which,
Q = quantity of flow, in cubic feet per second (cfs)
n = Manning Roughness Coefficient
A = cross-sectional area of flow, in square feet (ft^2)
S = longitudinal slope, in feet per foot (ft/ft)
R_h = hydraulic radius equals cross-sectional area of flow divided by the wetted perimeter, in feet (ft)

The most important factor in this flowmetering is the initial establishment of the equation variables. The $A R^{2/3}$ component of the Manning Equation can be instantaneously determined by utilizing a depth sensor on an incremental basis. A velocity probe was used to obtain the average cross-sectional velocity of the flow in an effort to establish the $S^{.5}$ constant in the equation for velocity: $V = \frac{1.486}{n} S^{.5} \times R_h^{0.67}$. A V-notch weir was used to measure the instantaneous quantity of flow to verify values obtained.

Periodically each flowmeter installation was visited by a field crew to ensure that the unit was operating correctly and to calibrate the output; calibration was performed by manually measuring the actual depth and velocity of flow over a range of depths, calculating the discharge, and comparing this value with the flowmeter output. Output data, along with its analysis and evaluation, is presented in the body of this report. Selection of metering locations is critical to obtaining reliable data. Line surcharging, cross-section irregularities, etc. could cause erroneous information.

The consultant accompanied by city personnel performed flowmetering after rehabilitation in test-and-seal and point repair test sections in order to establish the effectiveness of the technique in reducing infiltration values. Basically each section metered was isolated by plugging on the upstream end, with a 90-degree V-notch weir used to measure infiltration at the downstream manhole; sections were selected in which services were not present or where they were limited to the point where tributary flows could be controlled during testing.

Flowmetering of the LaGrange Highlands Sanitary District sliplining project for the determination of before-and-after flow and infiltration characteristics will be addressed in Section 4 of this report.

Test Section Selection

The next step in the investigation consisted of the establishment of representative test sections for each sewer rehabilitation option utilized in Hagerstown. Five (5) sewer sections of varying diameters and conditions scheduled for the testing and sealing of joints were selected for detailed analysis; due to field revisions of the techniques employed necessitated by conditions encountered, these test-and-seal test sections had to be relocated several times over the course of the study, such that a variation in line sizes could not be attained. The relocation of test sections also rendered the majority of the groundwater gauges installed prior to rehabilitation useless.

Five (5) sewer segments in which lining was contemplated were selected for "Insituform" study; test sections were comprised of lines of varying sizes, lengths, depths, locations and material in order to give a cross section of gravity applications for the product.

Point repair work was performed "in-house" by the City of Hagerstown Water Pollution Control Department staff, most times ahead of grouting and lining crews; since this work was not contracted out, costs attributed to this procedure may be slightly misleading. Point repair study sections were limited to lines where both point repair and grouting were performed, so that the effectiveness of each technique could not be determined except on a composite basis.

Conventional polyethylene sliplining methods were studied at a site in LaGrange Highlands, Illinois. This product was installed by the LaGrange Highlands Sanitary District in a relatively shallow line subject to large amounts of infiltration through joints. Consultant staff was used to investigate this situation.

Questionnaires

The consultant prepared four (4) separate very detailed Inspector Checklists, each specifically tailored to the type of rehabilitation being inspected. City staff, as well as project engineer inspectors, were asked to cooperate with the consultant by filling out these forms in entirety during construction activities and returning them to the author for review.

Figure 1 is a copy of the Inspector Checklist designed for use in line grouting work. Major factors of concern which are considered in this questionnaire are the weather, site location, ground water level, the size, depth, length and type of sewer line, the line condition and the necessity of any preliminary preparation including flow bypassing, the length of time users were without service, visible effectiveness of repair, the methods and materials used for the testing and sealing of joints, the total costs of rehabilitation, and the impact the work had upon the environment.

The field form for "Insituform" lining (Figure 2) includes most of the items covered in the sealing questionnaire, but additional information was requested on preparation of the liner, inversion and curing procedures and problems, the number of services reinstated and the means by which this was done, and on post-rehabilitation appearance of the liner. The great majority of these forms were filled out by consultant personnel at the site, and were very complete.

Like "Insituform," the Sliplining Inspectors Checklist (Figure 3) is much the same as that for sewer sealing. Information regarding the staging requirements for sliplining is obtained through the report; details of the material properties and the installation methods were also studied. Inspection of this technique was also performed by field technicians on the staff of the consultant and is very complete.

The Point Repair Checklist included as Figure 4 of this report attempts to take account of various factors such as weather, soil and ground water conditions, location of the repair, sewer diameter, depth, type and condition, any overpumping requirements, times of service disruptions, and traffic control required. Since this phase of the rehabilitation work was performed by city forces, construction and related costs were not considered. The preparation and filing of Point Repair Checklists was the responsibility of the point repair crew.

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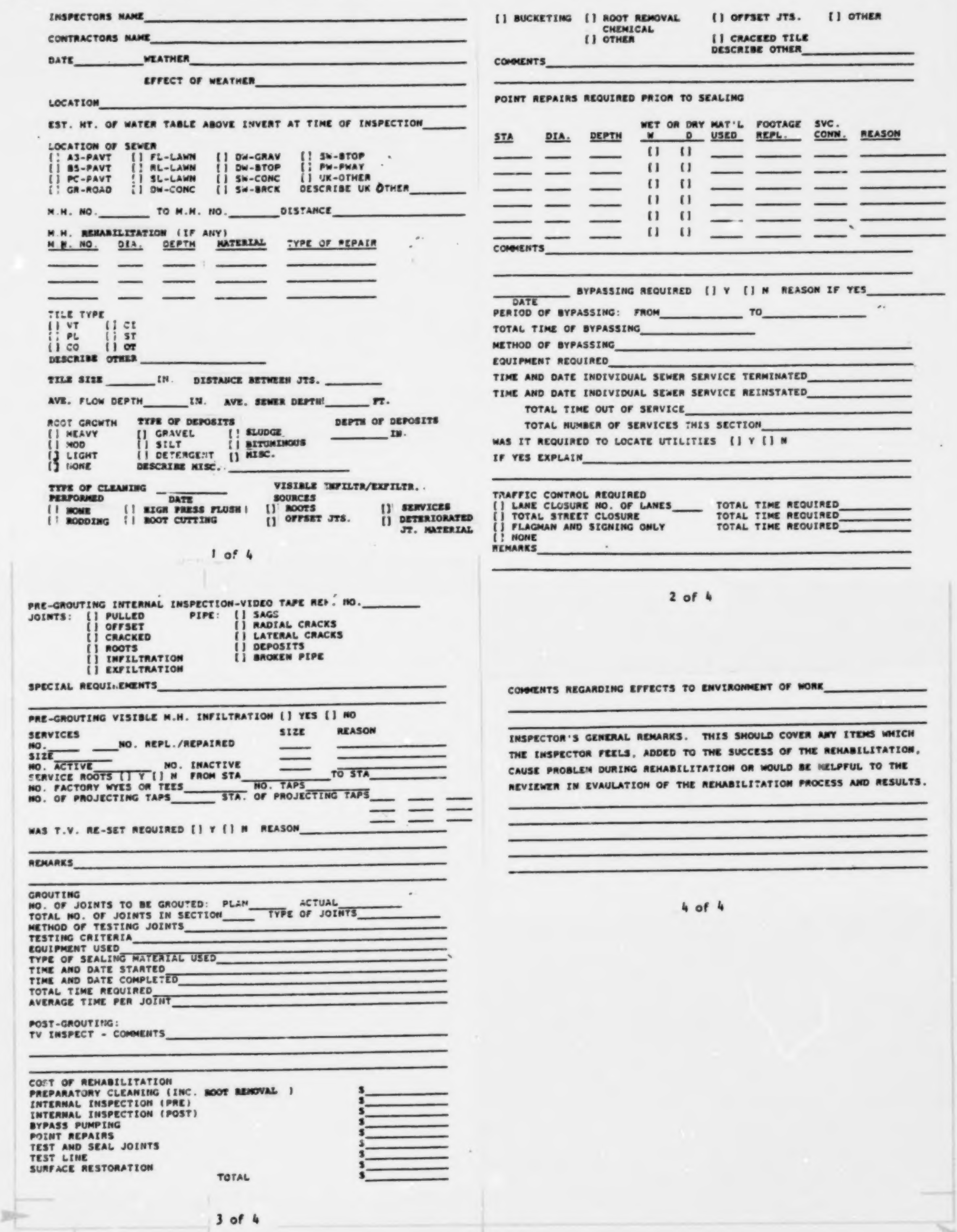
Figure 1: Inspectors Checklist Sewer Sealing



INSPECTORS NAME____________________

CONTRACTORS NAME____________________

DATE__________WEATHER____________________

EFFECT OF WEATHER____________________

LOCATION____________________

EST. HT. OF WATER TABLE ABOVE INVERT AT TIME OF INSPECTION______

LOCATION OF SEWER

☐ A3-PAVT	☐ FL-LAWN	☐ DW-GRAV	☐ SW-BTOP
☐ BS-PAVT	☐ RL-LAWN	☐ DW-BTOP	☐ PW-PWAY
☐ PC-PAVT	☐ SL-LAWN	☐ SW-CONC	☐ UK-OTHER
☐ GR-ROAD	☐ DW-CONC	☐ SW-BRCK	DESCRIBE UK OTHER________

M.H. NO.________ TO M.H. NO.________DISTANCE____________________

M.H. REHABILITATION (IF ANY)

M.H. NO.	DIA.	DEPTH	MATERIAL	TYPE OF REPAIR

TILE TYPE

☐ VT	☐ CI
☐ PL	☐ ST
☐ CO	☐ OT

DESCRIBE OTHER____________________

TILE SIZE ________IN. DISTANCE BETWEEN JTS. ________

AVE. FLOW DEPTH_______IN. AVE. SEWER DEPTH_______FT.

ROOT GROWTH	TYPE OF DEPOSITS		DEPTH OF DEPOSITS
☐ HEAVY	☐ GRAVEL	☐ SLUDGE	________IN.
☐ MOD	☐ SILT	☐ BITUMINOUS	
☐ LIGHT	☐ DETERGENT	☐ MISC.	
☐ NONE	DESCRIBE MISC.________		

TYPE OF CLEANING PERFORMED __________ DATE

☐ NONE ☐ HIGH PRESS FLUSH

☐ RODDING ☐ ROOT CUTTING

VISIBLE INFILTR/EXFILTR. SOURCES

☐ ROOTS ☐ SERVICES

☐ OFFSET JTS. ☐ DETERIORATED JT. MATERIAL

1 of 4

☐ BUCKETING ☐ ROOT REMOVAL CHEMICAL ☐ OFFSET JTS. ☐ OTHER

☐ OTHER ☐ CRACKED TILE

DESCRIBE OTHER________________

COMMENTS____________________

POINT REPAIRS REQUIRED PRIOR TO SEALING

STA	DIA.	DEPTH	WET OR DRY W	D	MAT'L USED	FOOTAGE REPL.	SVC. CONN.	REASON
			☐	☐				
			☐	☐				
			☐	☐				
			☐	☐				
			☐	☐				
			☐	☐				

COMMENTS____________________

__________ BYPASSING REQUIRED ☐ Y ☐ N REASON IF YES__________
DATE

PERIOD OF BYPASSING: FROM__________ TO__________

TOTAL TIME OF BYPASSING______________

METHOD OF BYPASSING____________________

EQUIPMENT REQUIRED____________________

TIME AND DATE INDIVIDUAL SEWER SERVICE TERMINATED______________

TIME AND DATE INDIVIDUAL SEWER SERVICE REINSTATED______________

TOTAL TIME OUT OF SERVICE____________________

TOTAL NUMBER OF SERVICES THIS SECTION______________

WAS IT REQUIRED TO LOCATE UTILITIES ☐ Y ☐ N

IF YES EXPLAIN____________________

TRAFFIC CONTROL REQUIRED

☐ LANE CLOSURE NO. OF LANES____	TOTAL TIME REQUIRED__________
☐ TOTAL STREET CLOSURE	TOTAL TIME REQUIRED__________
☐ FLAGMAN AND SIGNING ONLY	TOTAL TIME REQUIRED__________
☐ NONE	

REMARKS____________________

2 of 4

PRE-GROUTING INTERNAL INSPECTION-VIDEO TAPE REF. NO.________

JOINTS:	☐ PULLED	PIPE:	☐ SAGS
	☐ OFFSET		☐ RADIAL CRACKS
	☐ CRACKED		☐ LATERAL CRACKS
	☐ ROOTS		☐ DEPOSITS
	☐ INFILTRATION		☐ BROKEN PIPE
	☐ EXFILTRATION		

SPECIAL REQUIREMENTS____________________

PRE-GROUTING VISIBLE M.H. INFILTRATION ☐ YES ☐ NO

SERVICES	SIZE	REASON
NO._____ _____NO. REPL./REPAIRED		
SIZE________		
NO. ACTIVE________ NO. INACTIVE		

SERVICE ROOTS ☐ Y ☐ N FROM STA______________TO STA__________

NO. FACTORY WYES OR TEES__________ NO. TAPS__________

NO. OF PROJECTING TAPS_______ STA. OF PROJECTING TAPS___ ___ ___

WAS T.V. RE-SET REQUIRED ☐ Y ☐ N REASON____________________

REMARKS____________________

GROUTING

NO. OF JOINTS TO BE GROUTED: PLAN______ ACTUAL__________

TOTAL NO. OF JOINTS IN SECTION_____ TYPE OF JOINTS__________

METHOD OF TESTING JOINTS____________________

TESTING CRITERIA____________________

EQUIPMENT USED____________________

TYPE OF SEALING MATERIAL USED____________________

TIME AND DATE STARTED____________________

TIME AND DATE COMPLETED____________________

TOTAL TIME REQUIRED____________________

AVERAGE TIME PER JOINT____________________

POST-GROUTING:

TV INSPECT - COMMENTS____________________

COST OF REHABILITATION

PREPARATORY CLEANING (INC. ROOT REMOVAL)	$________
INTERNAL INSPECTION (PRE)	$________
INTERNAL INSPECTION (POST)	$________
BYPASS PUMPING	$________
POINT REPAIRS	$________
TEST AND SEAL JOINTS	$________
TEST LINE	$________
SURFACE RESTORATION	$________
TOTAL	$________

3 of 4

COMMENTS REGARDING EFFECTS TO ENVIRONMENT OF WORK______________

INSPECTOR'S GENERAL REMARKS. THIS SHOULD COVER ANY ITEMS WHICH THE INSPECTOR FEELS, ADDED TO THE SUCCESS OF THE REHABILITATION, CAUSE PROBLEM DURING REHABILITATION OR WOULD BE HELPFUL TO THE REVIEWER IN EVAULATION OF THE REHABILITATION PROCESS AND RESULTS.

4 of 4

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Figure 2: Inspectors Checklist Insituform Lining

INSPECTORS NAME____________________

DATE________ WEATHER____________________

ADDRESS OF SEWER____________________

EST. HT. OF WATER TABLE ABOVE INVERT AT TIME OF INSPECTION________

LOCATION OF SEWER
- ☐ A3-PAVT
- ☐ B5-PAVT
- ☐ PC-PAVT
- ☐ GR-ROAD
- ☐ FL-LAWN
- ☐ RL-LAWN
- ☐ SL-LAWN
- ☐ DW-CONC
- ☐ DW-GRAV
- ☐ DW-BTOP
- ☐ SW-CONC
- ☐ SW-BRCK
- ☐ SW-BTOP
- ☐ PW-PWAY
- ☐ UK-OTHER

DESCRIBE UK OTHER________

M.H. NO.______ TO M.H. NO.______ DISTANCE____________

TILE TYPE
- ☐ VT
- ☐ PL
- ☐ CO
- ☐ CI
- ☐ ST
- ☐ OT

DESCRIBE OTHER____________

TILE SIZE______IN. DISTANCE BETWEEN JTS.______

AVE. FLOW DEPTH______IN. AVE. SEWER DEPTH______FT.

ROOT GROWTH
- ☐ HEAVY
- ☐ MOD
- ☐ LIGHT
- ☐ NONE

TYPE OF DEPOSITS
- ☐ GRAVEL
- ☐ SILT
- ☐ DETERGENT
- ☐ SLUDGE
- ☐ BITUMINOUS
- ☐ MISC.

DESCRIBE MISC.________

DEPTH OF DEPOSITS
_______IN.

TYPE OF CLEANING PERFORMED
- ☐ NONE
- ☐ RODDING
- ☐ BUCKETING
- ☐ HIGH PRESS FLUSH
- ☐ ROOT CUTTIN
- ☐ OTHER

VISIBLE INFILTR/EXFILTR. SOURCES
- ☐ ROOTS
- ☐ OFFSET JTS.
- ☐ CRACKED TILE
- ☐ SERVICES
- ☐ DETERIORATED JT. MATERIAL
- ☐ OTHER

DESCRIBE OTHER __________

METHOD OF BYPASSING ____________________

EQUIPMENT REQUIRED ____________________

TIME AND DATE BYPASSING STARTED ________________

TIME AND DATE BYPASSING STOPPED ________________

TOTAL TIME OF BYPASSING ________________

TIME AND DATE INDIVIDUAL SEWER SERVICE TERMINATED __________

TIME AND DATE INDIVIDUAL SEWER SERVICE REINSTATED __________

TOTAL TIME OUT OF SERVICE ________________

TOTAL NUMBER OF SERVICES THIS SECTION __________

TRAFFIC CONTROL REQUIRED
- ☐ LANE CLOSURE NO. OF LANES ___ TOTAL TIME REQUIRED________
- ☐ TOTAL STREET CLOSURE TOTAL TIME REQUIRED________
- ☐ FLAGMAN AND SIGNING ONLY TOTAL TIME REQUIRED________
- ☐ NONE

REMARKS ______________________________

____

1 of 4

TIME REQUIRED TO ERECT SCAFFOLD
HEIGHT OF SCAFFOLD ABOVE GROUND______FT.
HEIGHT OF SCAFFOLD ABOVE SEWER INVERT______FT.

SOURCE OF INVERSION WATER
- ☐ F.H. PUBLIC WATER SUPPLY
- ☐ PUMPER TRUCK
- ☐ SURFACE WATER

REMARKS (SPECIAL PROBLEM, ETC.)____________________

____

BAG LENGTH______FT.

BAG THICKNESS_______MIL. NO. OF LAYERS______

BAG WETTED DOWN ON SITE ☐

BAG WETTED DOWN OFFSITE ☐

TIME AND DATE BAG WETTED_______(A.M.)(P.M.)

TIME AND DATE INVERSION STARTED_______(A.M.)(P.M.)

TIME AND DATE INVERSION COMPLETED________(A.M.)(P.M.)

TIME AND DATE CIRCULATION STARTED______(A.M.)(P.M.)INITIAL TEMP.____°F

TIME AND DATE 180°F TEMPERATURE REACHED_______(A.M.)(P.M.)

TIME AND DATE COOL DOWN STARTED________(A.M.)(P.M.)

TOTAL TIME FROM START OF CIRCULATION TO 180°F________

TOTAL TIME FROM WET DOWN OF BAG TO START OF COOL DOWN________

HEAT EXCHANGER BTU OUT BTU/HR._______

ESTIMATE CIRCULATION RATE______GPM

PRE INSITUFORM INTERNAL INSPECTION VIDEO TAPE REF. NO._______

JOINTS:
- ☐ PULLED
- ☐ OFFSET
- ☐ CRACKED
- ☐ ROOTS
- ☐ INFILTRATION
- ☐ EXFILTRATION

PIPE:
- ☐ SAGS
- ☐ RADIAL CRACKS
- ☐ LATERAL CRACKS
- ☐ DEPOSITS
- ☐ BROKEN PIPE

PRE INSITUFORM VISIBLE M.H. INFILTRATION ☐ YES ☐ NO

SERVICES
NO._____
SIZE_____
NO. ACTIVE______
NO. INACTIVE______
SERVICE ROOTS______
NO.FACTORY WYES OR TEES_______
NO.TAPS______
NO. OF PROJECTING TAPS______
NO. SERVICES REQUIREING DIG-UP PRIOR TO LINING________
REMARKS______________________________

____

____

____

2 of 4

POST-INSITUFORM INTERNAL INSPECTION VIDEO TAPE REF. NO._______

LINER
PIPE INVERT: ☐ SMOOTH ☐ WRINKLED
PIPE WALLS: ☐ SMOOTH ☐ WRINKLED

REMARKS______________________________

CHANGE IN SUBSIDENCE OF BROKEN PIPE.

REMARKS______________________________

NO. OF SERVICES REINSTATED______

AVE. TIME TO CUT OUT SERVICE_______

INSPECTORS GENERAL REMARKS. THIS SHOULD COVER ANY ITEMS WHICH THE INSPECTOR FEELS, ADDED TO THE SUCCESS OF THE REHABILITATION, CAUSE PROBLEM DURING REHABILITATION OR WOULD BE HELPFUL TO THE REVIEWER IN EVAULATION OF THE REHABILITATION PROCESS AND RESULTS.

____

____

____

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____

3 of 4

TIME AND TEMPERATURE RECORD.

THE TIME AND TEMPERATURE SHALL BE RECORDED AT 15 MINUTE INTERVALS AT 4 DEFINATE LOCATIONS. *THE INSPECTOR SHALL ALSO MAKE NOTE OF THE TIME THE HEAT EXCHANGER IS FIRED, SHUT DOWN, COOLING WATER ADDED AND ANY OTHER KEY TIME DURING CURING OPERATION.

*KEY OPER.	TIME	TEMP. INTO HEAT EXCHANGER	TEMP. OUT OF HEAT EXCHANGER	TEMP. NEAR THERMOL COUPLE	TEMP. FOR THERMAL COUPLE

4 of 4

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Figure 3: Inspectors Checklist Sliplining

INSPECTORS NAME____________________

DATE__________WEATHER____________________

EST. HT. OF WATER TABLE ABOVE INVERT AT TIME OF SINPECTION______

LOCATION OF SEWER
[] A3-PAVT
[] BS-PAVT
[] PC-PAVT
[] GR-ROAD
[] FL-LAWN
[] RL-LAWN
[] SL-LAWN
[] DW-CONC
[] DW-GRAY
[] DW-BTOP
[] SW-CONC
[] SW-BRCK
[] SW-BTOP
[] PW-PWAY
[] UK-OTHER
DESCRIBE UK OTHER________

M.H. NO.________TO M.H. NO.________DISTANCE________________

TILE TYPE
[] VT
[] PL
[] CO
[] CI
[] ST
[] OT
DESCRIBE OTHER________________

TILE SIZE________IN. DISTANCE BETWEEN JTS. _________

AVE. FLOW DEPTH ________IN. AVE. SEWER DEPTH_______FT.

ROOT GROWTH
[] HEAVY
[] MOD
[] LIGHT
[] NONE

TYPE OF DEPOSITS
[] GRAVEL
[] SILT
[] DETERGENT
[] SLUDGE
[] BITUMINOUS
[] MISC.
DESCRIBE MISC.______________

DEPTH OF DEPOSITS
__________IN.

TYPE OF CLEANING
PERFORMED
[] NONE
[] RODDING
[] BUCKETING
[] HIGH PRESS FLUSH
[] ROOT CUTTING
[] OTHER

VISIBLE INFILTR EXFILTR.
SOURCES
[] ROOTS
[] OFFSET JTS.
[] CRACKED TILE
[] SERVICES
[] DETERIORATED JT. MATERIAL
[] OTHER
DESCRIBE OTHER________________

PRE LINING INTERNAL INSPECTION VIDEO TAPE REF. NO. ______________
JOINTS:
[] PULLED
[] OFFSET
[] CRACKED
[] ROOTS
[] INFILTRATION
[] EXFILTRATION
PIPE:
[] SAGS
[] RADIAL CRACKS
[] LATERAL CRACKS
[] DEPOSITS
[] BROKEN PIPE

PRE LINING VISIBLE: M.H. INFILTRATION: [] YES [] NO

SERVICES
NO. ______
SIZE________
NO. ACTIVE ________

1 of 4

NO. INACTIVE________
SERVICE ROOTS________
NO. FACTORY WYES OR TEES________
NO. TAPS________
NO. OF PROJECTING TAPS________
NO. SERVICES REQUIRING DIG-UP PRIOR TO LINING________
REMARKS____________________

____

____

METHOD OF BYPASSING(IF Required)____________________

EQUIPMENT REQUIRED FOR BYPASSING____________________

TIME AND DATE BYPASSING STARTED____________________

TIME AND DATE BYPASSING STOPPED____________________

TOTAL TIME OF BYPASSING____________________

TIME AND DATE INDIVIDUAL SEWER SERVICE TERMINATED______________

TIME AND DATE INDIVIDUAL SEWER SERVICE REINSTATED______________

TOTAL TIME OUT OF SERVICE____________________

TOTAL NUMBER OF SERVICES THIS SECTION______________

TRAFFICE CONTROL REQUIRED
[] LANE CLOSURE NO. OF LANES____ TOTAL TIME REQUIRED__________
[] TOTAL STREET CLOSURE TOTAL TIME REQUIRED__________
[] FLAGMAN AND SIGNING ONLY TOTAL TIME REQUIRED__________
[] NONE
REMARKS____________________

____

ACCESS EXCAVATION FOR SLIP LINING
DIMENSION OF EXCAVATION AT THE SURFACE________WIDTH FT. x ______
LENGTH.

DEPTH OF EXCAVATION____________________

DID ACCESS EXCAVATION REQUIRE ANY SHEET AND/OR BRACING. [] YES [] NO
IF YES EXPLAIN____________________

____

HOW MUCH OF THE TOP OF PIPE WAS REMOVED FOR INSERTION OF THE LINER ________FT. WAS ANYTHING DONE TO REINFORCE THE LOWER HALF OF THE PIPE IN THE AREA OF INSERTION AFTER THE TOP HALF OF THE PIPE HAD BEEN REMOVED.____________________

____

2 of 4

[] FLEXIBLE PULL HEAD
[] RIGID PULL HEAD

WAS A PULL MADE IN BOTH DIRECTION FROM ACCESS EXCAVATION. [] YES [] NO
LENGTH OF FIRST PULL__________FT.
LENGTH OF SECOND PULL__________FT.

PHYSICAL PROPERTIES OF LINER PIPE
MFG.____________________
OD__________IN. ID__________IN. WALL THICKNESS____________IN.
SDR NO.________
WAS THE ORIGINALLY SPECIFIED LINER PIPE USED. [] YES [] NO
IF NO, EXPLAIN WHY ALTERNATE LINE PIPE WAS USED______________

____

WAS THE ENTIRE LENGTH JOINED BY BUTT FUSION TECHNIQUE. [] YES [] NO
IF NO, EXPLAIN METHOD OF CONNECTING THE TWO LONG LENGTHS OF PIPE.

____

____

HOW LONG A PERIOD OF TIME WAS THE LINER ALLOWED TO REACH EQUILIBRIUM FROM THE EFFECTS OF PULLING AND TEMPERATURE CHANGE.
TOTAL LENGTH OF PIPE________FT.
CHANGE IN LENGTH OF PIPE________FT.(LONGER OR SHORTER)

SEALING LINER AT MANHOLE
DESCRIBE METHOD AND MATERIAL USED TO SEAL LINER AT MANHOLE______

____

____

METHOD OF RECONNECTING EXISTING SERVICE CONNECTIONS.
[] SADDLE [] REMOTE TAPPING SYSTEM [] OTHER
IF OTHER OR REMOTE TAPPING SYSTEM EXPLAIN METHOD USED.________

____

____

IF SADDLES WERE USED ON WHAT SIZE PIPE WERE SADDLES WITH A BOTTOM HALF USED.____________________

DESCRIBE MATERIALS USED, INCLUDING ANY ADAPTORS (TYPE) AND/OR COUPLING (TYPE) USED TO RECONNECT SERVICES______________

____

____

DURING THE RECONNECTING OF THE EXISTING SERVICES WHAT WAS THE AVERAGE LENGTH OF NEW PIPE LAID?________FT.

3 of 4

INSPECTORS GENERAL REMARKS. THIS SHOULD COVER ANY ITEMS WHICH THE INSPECTOR FEELS, ADDED TO THE SUCCESS OF THE REHABILITATION, CAUSE PROBLEM DURING REHABILITATION OR WOULD BE HELPFUL TO THE REVIEWER IN EVALUATION OF THE REHABILITATION PROCESS AND RESULTS.

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4 of 4

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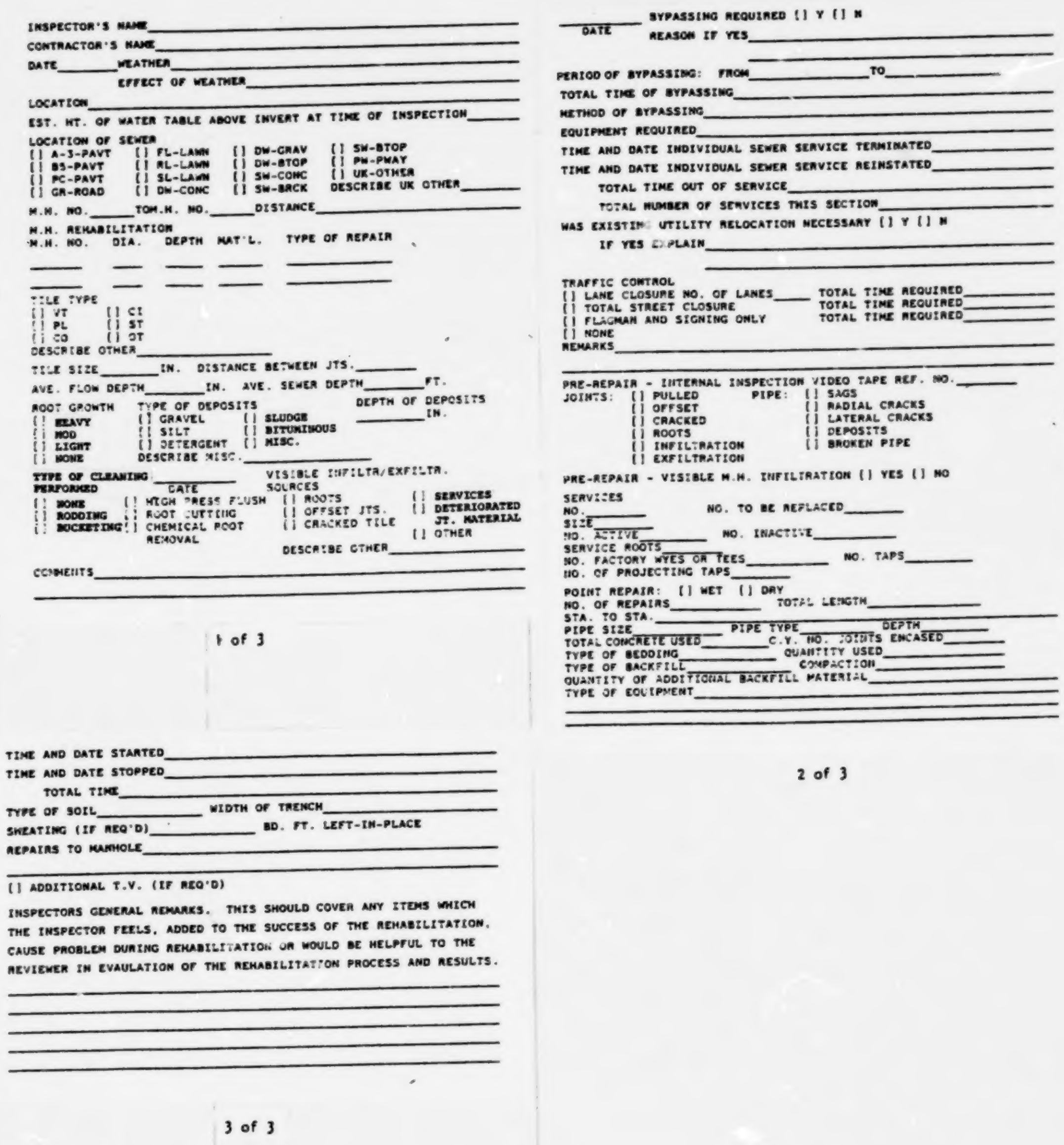
Figure 4: Inspectors Checklist Point Repairs



INSPECTOR'S NAME____________________

CONTRACTOR'S NAME____________________

DATE________ WEATHER____________________

EFFECT OF WEATHER____________________

LOCATION____________________

EST. HT. OF WATER TABLE ABOVE INVERT AT TIME OF INSPECTION______

LOCATION OF SEWER
[] A-3-PAVT [] FL-LAWN [] DW-GRAV [] SW-BTOP
[] BS-PAVT [] RL-LAWN [] DW-BTOP [] PW-PWAY
[] PC-PAVT [] SL-LAWN [] SW-CONC [] UK-OTHER
[] GR-ROAD [] DW-CONC [] SW-BRCK DESCRIBE UK OTHER________

M.H. NO.______ TOM.H. NO.______ DISTANCE____________________

M.H. REHABILITATION

M.H. NO.	DIA.	DEPTH	MAT'L.	TYPE OF REPAIR
______	___	____	_____	____________
______	___	____	_____	____________

TILE TYPE
[] VT [] CI
[] PL [] ST
[] CO [] OT
DESCRIBE OTHER________________

TILE SIZE________IN. DISTANCE BETWEEN JTS.________

AVE. FLOW DEPTH________IN. AVE. SEWER DEPTH________FT.

ROOT GROWTH
[] HEAVY
[] MOD
[] LIGHT
[] NONE

TYPE OF DEPOSITS
[] GRAVEL [] SLUDGE
[] SILT [] BITUMINOUS
[] DETERGENT [] MISC.
DESCRIBE MISC.________________

DEPTH OF DEPOSITS
________IN.

TYPE OF CLEANING PERFORMED ____________ DATE
[] NONE [] HIGH PRESS FLUSH
[] RODDING [] ROOT CUTTING
[] BUCKETING [] CHEMICAL ROOT REMOVAL

VISIBLE INFILTR/EXFILTR. SOURCES
[] ROOTS [] SERVICES
[] OFFSET JTS. [] DETERIORATED JT. MATERIAL
[] CRACKED TILE [] OTHER
DESCRIBE OTHER________________

COMMENTS____________________

____

1 of 3

________ DATE
BYPASSING REQUIRED [] Y [] N
REASON IF YES____________________

____

PERIOD OF BYPASSING: FROM____________TO____________

TOTAL TIME OF BYPASSING____________________

METHOD OF BYPASSING____________________

EQUIPMENT REQUIRED____________________

TIME AND DATE INDIVIDUAL SEWER SERVICE TERMINATED____________

TIME AND DATE INDIVIDUAL SEWER SERVICE REINSTATED____________

TOTAL TIME OUT OF SERVICE____________________

TOTAL NUMBER OF SERVICES THIS SECTION____________

WAS EXISTING UTILITY RELOCATION NECESSARY [] Y [] N

IF YES EXPLAIN____________________

____

TRAFFIC CONTROL
[] LANE CLOSURE NO. OF LANES____ TOTAL TIME REQUIRED________
[] TOTAL STREET CLOSURE TOTAL TIME REQUIRED________
[] FLAGMAN AND SIGNING ONLY TOTAL TIME REQUIRED________
[] NONE
REMARKS____________________

____

PRE-REPAIR - INTERNAL INSPECTION VIDEO TAPE REF. NO.________

JOINTS:
[] PULLED
[] OFFSET
[] CRACKED
[] ROOTS
[] INFILTRATION
[] EXFILTRATION

PIPE:
[] SAGS
[] RADIAL CRACKS
[] LATERAL CRACKS
[] DEPOSITS
[] BROKEN PIPE

PRE-REPAIR - VISIBLE M.H. INFILTRATION [] YES [] NO

SERVICES
NO.________ NO. TO BE REPLACED________
SIZE________
NO. ACTIVE________ NO. INACTIVE________
SERVICE ROOTS________
NO. FACTORY WYES OR TEES________ NO. TAPS________
NO. OF PROJECTING TAPS________

POINT REPAIR: [] WET [] DRY
NO. OF REPAIRS________ TOTAL LENGTH________
STA. TO STA.____________________
PIPE SIZE________ PIPE TYPE________ DEPTH________
TOTAL CONCRETE USED________C.Y. NO. JOINTS ENCASED________
TYPE OF BEDDING________ QUANTITY USED________
TYPE OF BACKFILL________ COMPACTION________
QUANTITY OF ADDITIONAL BACKFILL MATERIAL________
TYPE OF EQUIPMENT____________________

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2 of 3

TIME AND DATE STARTED____________________

TIME AND DATE STOPPED____________________

TOTAL TIME____________________

TYPE OF SOIL____________ WIDTH OF TRENCH____________

SHEATING (IF REQ'D)____________ BD. FT. LEFT-IN-PLACE

REPAIRS TO MANHOLE____________________

____

[] ADDITIONAL T.V. (IF REQ'D)

INSPECTORS GENERAL REMARKS. THIS SHOULD COVER ANY ITEMS WHICH THE INSPECTOR FEELS, ADDED TO THE SUCCESS OF THE REHABILITATION, CAUSE PROBLEM DURING REHABILITATION OR WOULD BE HELPFUL TO THE REVIEWER IN EVAULATION OF THE REHABILITATION PROCESS AND RESULTS.

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3 of 3

EPA Form 2350-4 (4-80)
TYPING GUIDE SHEET

Division of Responsibility

The lead agency involved with initiating the data gathering and preparation of this report is the City of Hagerstown Water Pollution Control Department; this department applied for and obtained a partial funding commitment for the study from the Federal Environmental Protection Agency. The Water Pollution Control Department staff then contacted technical consultants to coordinate and perform the study, but was itself responsible for management of the program. City inspectors were responsible for documenting all construction problems, procedures, and costs for each technique on forms supplied by the Research Consultant.

Responsibilities of the Research Consultant included assistance in the selection of representative test sections for each rehabilitation method studied; the Research Consultant was also responsible for the preparation of the previously presented test section checklists. Prior to the commencement of construction, the consultant sent a crew to Hagerstown, Maryland to install ground water gauges at each test section and to instruct city personnel on the monitoring of these gauges; city staff was to record readings of these gauges as well as rainfall data and to present same to the Research Consultant.

The research crew also field determined the grades in each proposed test segment, as well as verifying conduit sizes and types.

The Research Consultant also attended a meeting at which the city, the EPA, and the flowmetering subconsultant were present to establish criteria for "before-and-after" test section flowmetering. Metering was to be performed for a period of two (2) weeks prior to rehabilitation in key manholes upstream and downstream from the test section, and also two (2) weeks after repair had been completed; scheduling problems did create some inconsistencies in meeting these goals but, overall the metering was acceptable in the "Insituform" sections; other manual plug-and-weir methods of metering in Hagerstown appeared to be very representative of site conditions at the time performed.

The Research Consultant was responsible for the site investigation and documentation of a conventional sliplining site in Illinois, including the determination of before-and-after flow characteristics and infiltration values, and the development of a cost analysis for the work.

Finally the Research Consultant was responsible for the assemblage and review of all data and documentation and to prepare a comprehensive report which compares the rehabilitation alternatives studied, recommends a procedure for the proper installation of "Insituform," and evaluates the possibility of renovating private services using "Insituform."

The flowmetering subconsultant had the responsibility of installing, calibrating, and monitoring automatic recording flowmeters in key manholes upstream and downstream of selected test sections before and after repair was performed. Information provided to the Research Consultant was to be of such a nature to facilitate the calculation of before-and-after test section flow properties and technique effectiveness. Limitations of the flowmetering equipment necessitated relocating some test sections, and provided very limited isolated test section data on test-and-seal and point repair sections. Therefore a crew from the consultant was sent to gather infiltration quantities on test-and-seal and point repair lines after the rehabilitation was complete; this flowmetering was performed within one (1) to two (2) days following a 6-inch (15.2 cm) rainfall event in an area with a very high ground water table.

ALTERNATIVES

Generally speaking, four (4) different sewer main repair alternatives were studied in this survey: (1) Testing and sealing of mainline joints and radial cracks with chemical grout materials; (2) Point repair of badly cracked or broken pipe sections (performed in-house); (3) Lining sewers from manhole to manhole using the conventional polyethylene liner technique; and (4) Lining sewers from manhole to manhole utilizing the "Insituform" product. The City of Hagerstown Sewer System Evaluation Survey presented cost-effective justification for each option implemented in the location where it was used. Each of the techniques used will be compared in detail in the following paragraphs; as a preface, it should be noted that prior to performing any type of sewer repair, the line should be cleaned and televised to verify the extent of the problem and its exact location.

Procedures and Equipment

Test-and-Seal - In Hagerstown, sewer joints and radial cracks suspected of being defective, as evidenced in earlier closed-circuit television internal inspections, were selectively water-tested and, where required, sealed using an acrylamide grout. Basically in this operation a camera and packer assembly is dragged through a sewer line to a point at which the packer unit straddles a suspected joint. When the packer is in position, bladders at either end are inflated to seal off the joint, and water is pumped at a defined rate into the annular space between the packer and the pipe; should the pressure in the annular space not rise to a prescribed level, the joint is described as failing the test. The sealing compound is then pumped through two (2) separate lines to the annular space where the components of each line are mixed creating a gelling reaction which thereby seals the defective joint. The joint is retested as previously described and if the test is successful, the assembly is pulled to the next defective joint. The concentrations and components used in the grout can be changed to more satisfactorily meet the conditions of each situation. Very specialized and highly technical equipment requiring a high degree of maintenance is necessary to perform testing and sealing.

Point Repairs - All point repairs of crushed or broken pipe were performed by city forces with municipal or rented equipment. The damaged section of sewer is exposed using a backhoe to a point whereby satisfactory undamaged pipe is noted at each end. The damaged pieces of pipe are then removed and replaced with conduit of a similar or compatible type and size using couplings specifically designed for each application. Finally surface restoration is performed; this last item may be extremely costly and demanding depending upon the location of the work.

Point repair work can generally be accomplished without the investment of technical manpower or complex equipment, and therefore lends itself to a force account application; however, where very large or deep lines are encountered, or where flow bypassing or complex restoration tasks are required the work is generally contracted out.

Conventional Polyethylene Sliplining - Sliplining is the pulling of a high-density polyethylene sewer pipe into the existing sewer line, thus providing a new sewer line. When performed correctly, conventional sliplining is a very effective means by which to eliminate infiltration from a sewer main; although the concept is relatively simple (that of pulling a slightly flexible plastic liner through a deteriorated sewer section), the process does require some relatively complex equipment. Prior to any lining, the stretch must be televised to verify that the liner may clear any protrusions and offset joints; hindrances must be exposed and corrected in advance of lining. Initially a staging pit, from which the liner is inserted into the sewer, is excavated at some convenient location such as a manhole or sewer service; this pit may become very extensive in deep or large diameter installations. Sections of the liner are then butt-fused together on the surface using a specially-designed joining jig. In the fusion process the two surfaces being joined are melted and forced together under pressure, creating a homogeneous high strength interface. The unit utilized for butt-fusion consists of a facing tool to ensure proper alignment of pipe ends, a heating plate to soften interface material at a temperature between 475 degrees Fahrenheit (246 degrees Centigrade) and 500 degrees Fahrenheit (260 degrees Centigrade). Depending upon the length and diameter of sewer to be lined, the staging area may approach enormous proportions. A high strength cable is then strung through the sewer, generally by using some type of sewer cleaning equipment or by floating a leader. One end of the cable is attached to a pulling harness which, in turn, is connected to the end of the liner, with the other end being fastened to a truck-mounted winch; the truck and winch slowly draw the liner through the deteriorated section to be rehabilitated until it is visible at the exit point of the segment. The harness is then removed and the liner, which is stretched during the installation process, is allowed to relax and return as closely as possible to its original length and cross-section. After shrinkage of the material has terminated, service connections are reinstated by means of excavating to expose the tap, cutting or breaking the pipe surrounding the tap, installing a heat fused or strap-on polyethylene saddle tee or wye, and reconnecting the original service using appropriate pipe, fittings and couplings. To prevent infiltration from entering the annular space between the sewer and the liner, the annulus around the service is filled with a non-shrinking grout material; additionally to block the passage of migrating extraneous clear waters from entering the collection system at manholes, the annular space between the original and liner conduits is sealed with grout at each manhole wall.

After the lining has been completed and tested all trenches are carefully backfilled and the surface restored.

"Insituform" Lining - Although the theory of "Insituform" is relatively straightforward, considerable planning and engineering is necessary which considers the variables that are present at each site. The technicalities involved with the inversion process are quite complex, and therefore the procedure will be discussed in detail.

The process consists of inverting a flexible felt liner treated with thermo-setting polyester or epoxy resins into a sewer by means of a static water head. Hot water is then circulated in the line, thus curing the resin impregnated liner. The procedure in many cases requires no excavation, thereby being of great advantage in densely build-up areas or other areas of high restoration costs.

Equipment:

The inversion platform used to provide a static water head to invert the liner consists of construction-type sectional scaffolding erected over the point of inversion. The inversion platform supports the inversion tube, workmen, liner, and recirculation hose during the inversion and curing phase of the installation. The height of the platform depends on the required inversion head and depth of sewer to be lined.

The inversion tube suspended from the platform consists of a reinforced polyester tube of sufficient diameter and length to allow the liner to pass from the top of the inversion platform to a steel inversion shoe located in the invert of the sewer to be lined. The top of the inversion tube is attached to a steel ring. This steel ring supports the inversion tube which hangs from the inversion platform on cross-members of the scaffolding.

The inversion shoe is a prefabricated 90-degree steel elbow of the appropriate diameter for the sewer being lined and the inversion tube being used. The inversion shoe is attached to the bottom end of the inversion tube by stainless steel straps. The "Insituform" liner is attached to the other end of the inversion shoe also by stainless steel straps.

A portable drum-type mixer is used to mix the appropriate catalyst with the non-promoted resin just prior to transferring the resin from the shipping barrels into the "Insituform" liner. A small transfer pump is used to transfer the catalyzed resin from the shipping barrels into the liner for complete impregnation of the felt.

A vacuum pump is necessary to evacuate the air from the "Insituform" liner liner prior to introducing the resin into the liner. It enhances the drawing of the resin into the felt. The requirement for a partial vacuum within the liner during this process emphasizes the need for a polyurethane liner covering which is entirely free of pinholes or defects.

The saturation conveyor system is a three-level conveyor through which the "Insituform" liner and resin are passed to ensure even distribution of the resin maerial throughout the entire liner length. Doctor, or squeeze, rollers are used at the top end of the conveyor to determine the proper resin saturation of the liner material throughout.

A lay-flat hose attached by rope to the closed end of the liner material is a high-pressure hose used to circulate hot water to the far end of the liner during the curing process. It must be able to withstand the very high temperature at which the boiler discharge is being recirculated for curing.

The hold back rope is also attached to the closed end of the liner, and is used to control the rate of inversion after the liner is half way into the line. If the liner inverts too swiftly, the water head may be lost in the inversion tube creating air pockets in the inversion water inside the liner that may cause an incomplete curing of the system in the area of the pocket. The rope is attached to the end of the liner away from the point of inversion by means of tape and wire. It is also used to help hold back the far end of the liner when it arrives at the desired termination of the inversion run.

A water supply line supplies water to the inversion tube by means of a control valve. In most situtions this hose is connected to a nearby fire hydrant using a meter arrangement.

The water control valve is located at the top of the inversion platform. It is used to control the height of the inversion head and thereby the rate of inversion; it is extremely important that the inversion head be maintained at a static level throughout inversion so that the liner proceeds at a relatively constant ra[illegible]hrough the sewer.

The curing water circulating pump is a pump used to circulate the water from the inversion tube to the heat exchanger, and then through the lay-flat hose to the far end of the sewer section being relined. A boiler and heat exchanger assembly is the source of heat used to bring the water for the inversion process up to the curing temperature of the thermo-setting resin.

The "Insitucutter" is a patented cutting device which allows the remote reinstatement of existing services by means of a drill apparatus which may be pulled through the relined sewer. The device is positioned and controlled by an operator utilizing a three-dimensional control system to cut out lining material in the service connections using the picture on a television monitor. The television monitor provides a picture received from the internal inspection camera located on a sled within the sewer just ahead of the cutter.

Thermocouples are temperature sensing devices placed between the liner material and the sewer wall which monitor temperature during the liner cure and post-cure periods. They give accurate indications of the cure status of the material since they are located in the area of the liner which cures last.

The liner itself is made from polyurethane-coated, polyester-fiber felt. It is made of densely-needled polyester fiber, and can vary in thickness from 1/8 to 1-7/8 in. (3 to 35 mm) in the prelining state. The liner is usually made of multiple layers of fiber of 1/8 in. (3 mm) each to give the desired total thickness. The primary function of the felt is to act as a substrate to hold the resin prior to curing. Each layer of felt is individually sewn into a long cylindrical tube of the proper length and diameter for the proposed lining application. Liners can be custom-designed and constructed for a perfect fit. A polyurethane coating is applied to the outer surface of the outer layer of material only. Its purpose is to provide an airtight membrane to enable a vacuum to be drawn on the liner during resin impregnation and to allow the circulation of curing water throughout the liner, as well as providing a smooth flow surface for the inverting process.

The polyester or epoxy resin is a thermo-setting material used to impregnate the polyester fiber felt liner. This material forms the actual smooth, resistant structure within the original conduit. The resin may contain certain additives to achieve specific characteristics required for each application.

A catalyst is the chemical compound which is added to the resin to initiate the reactive process of the compound and to assist in determining the curing temperature, life and hardness of the product. After the catalyst is added to the resin, the resin is considered to be in the promoted, or reactive state.

Installation Procedure:

The "Insituform" installation team generally consists of thirteen (13) men divided as follows: One general foreman, one 3-man preparatory cleaning crew, one 2-man crew for internal inspection and evaluation, one 4-man crew to install and cure the liner and one 3-man crew to reinstate the service laterals.

In addition, the "Insituform" installation team is assisted by a 3-man crew located in the wet-out area, or the area where resin is injected into the liner and distributed by means of the previously-described conveyor rollers; this 3-man crew can serve up to three installation teams.

The general foreman is responsible for coordinating the entire installation from initial preparatory cleaning to final inspection and clean up. The foreman may assign additional manpower as required to keep work on schedule.

The 3-man preparatory crew performs all necessary tasks to prepare the sewer for lining; this may require root removal, bucketing, swabbing or high pressure jetting. After the preparatory cleaning is completed, the 2-man internal inspection and evaluation team makes an inspection of the line to ascertain that the cleaning is complete and also to record on a TV log the location of all line deficiencies and service connections; this crew determines whether the sewer is suitable for lining. In addition to the TV log the line is in most cases video taped.

As soon as the internal inspection crew completes their work and establishes that the line is ready for lining, a 4-man installation crew starts erecting the inversion platform; this crew is responsible for the actual inversion and curing of the liner.

The inversion platform is constructed of structural steel tubing using standard scaffold frames and accessories. The scaffold height varies with the depth below grade and the diameter of the sewer being lined, as well as the thickness of the liner. The inversion heads may vary from a maximum of 38 feet (11.5 m) on a six millimeter thick, 8 inch (20 cm) diameter liner to as little as 12 feet (3.6 m) on a nine millimeter thick 24 inch (60 cm) diameter liner. The larger the diameter, the smaller the head needed for the inversion due the decreased effort needed to turn the larger liner inside out. Five to six feet (1.5 m - 2 m) below the top of the scaffold, a walk platform is installed for the workmen to stand on during the inversion. Eighteen inches (46 cm) below the top of the scaffolding an adjustable inversion tube support system is installed. This support system sustains the steel rings at the top of the inversion tube. At the very top of the scaffold a capstan is positioned to act as a pulley for the tag line or hold back rope.

Care must be taken when erecting the inversion platform to ensure that the feet of the scaffold legs are on good firm ground and that the scaffold is level in all directions. Some minimal excavation or footing construction may be necessary to provide the desired degree of safety.

At the same time the inversion platform is being erected, the liner is being prepared for insertion; there are several steps to be taken in this preparation phase. One of the first and ongoing procedures throughout the entire installation is the visual inspection of the liner for any obvious flaws such as pinholes or tears in the polyurethane coating. These defects may have been caused in manufacturing the liner, although flaws of this type would have most likely been detected earlier during quality control by the manufacturer. If there is a defect in the liner, it is much better to detect it before the liner is installed in the sewer than to realize that the recirculating water is leaking and curing is impossible; in the course of this study, the Amerock site was the only case where this problem was evident.

After the liner is unpacked from its shipping container, a vacuum pump is attached to the liner to evacuate the entrapped air from the felt liner material. This, in itself, gives a test as to the soundness of the liner since in a damaged liner, it would be impossible to draw and maintain a vacuum within the system.

While the air is being evacuated from the liner, the resin is being prepared by other workmen. As mentioned earlier, the resin is shipped to the job site unpromoted in drums. The resin is stored in the unpromoted state until just prior to use since it is much more stable and has a longer shelf life in the unpromoted condition.

Resin is generally shipped to the project site in removable lid type drums in order to facilitate mixing and transfer. The lids are removed from the drums and the prescribed amounts of catalysts are added, the ingredients thoroughly mixed with portable flash-type mixers. The lids are then replaced on the drums to await transfer of the resin into the liner. Care should be taken to keep the resin material away from direct exposure to sunlight; ultra-violet rays tend to deteriorate the composition of the material. Prolonged exposure in the presence of heat can possibly cause a thermo-setting reaction. The polyester resin may be kept in the catalyzed state for up to forty-eight (48) hours providing it is out of direct sunlight and below 40°F (4°C); the life of an epoxy resin is significantly longer.

Resin material must be liberally spread throughout the liner, replacing all the air in the "Insituform." Many times the activated resin contains a dye so that the spread of material throughout the liner can be verified. An air pocket in the liner, devoid of resin will not cure, and therefore a soft spot in the finished product will result.

The quantity and type of catalyst are determined based upon the proposed curing conditions, as well as the recommendations of the resin manufacturer. When the desired level of vacuum 5 to 8 pounds per square inch is reached on liner, it is ready to receive the catalyzed or promoted resin. The transfer of resin to the liner is accomplished by the use of a hydraulic transfer pump. The pump suction is placed in each drum and the contents of the drum are pumped into the line opposite the end of the liner to which the vacuum pump is attached. After all the promoted resin has been transferred to the liner, the liner is resealed at the ends.

The next step in the preparation of the liner is the saturation of the liner felt. An even and thorough saturation of the liner is very important to assure uniform strength and cure of the liner when in place. To assure the even distribution of resin throughout the liner, it is passed over a conveyor system. This variable speed system delivers the liner to the squeeze rollers at the proper speed to assure complete saturation of the felt liner. The doctor rollers are preset at the proper thickness to allow just the right amount of resin to pass through in order to assure an even distribution throughout the length of the liner. The process of saturating the liner felt with resin is referred to as wet-out.

For reasons previously stated, the saturated liner should be kept out of direct sunlight and at or below 40°F (4°C) during transportation and storage. The wet-out should not occur in excess of twenty-four hours before the estimated installation time when polyester resins are being utilized unless kept under refridgerated conditions. In most cases the wet-out area is planned within a few miles of the installation site.

After previously mentioned preparatory measures have been completed, overpumping of wastewater around the sewer segment to be repaired is initiated; generally the flow is pumped from a manhole one stretch upstream of the section to a manhole one stretch downstream.

After the inversion platform, inversion tube, and water supply hose are in place, the crew is ready for the wetted-out liner. Upon reaching the site, one end of the liner is cut off and folded over to make a triangular point and taped with duct tape in order to facilitate passing the liner through the inversion tube. The liner end is next passed over a roller conveyor to the top of the inversion platform and down the inversion tube until about 6 inches (15 cm) of the pointed end of the liner extends out of the inversion shoe. The duct tape is removed from the pointed end and the outer layer of polyurethane covered felt is folded back over the inversion shoe, and secured using stainless steel banding.

The water is now turned on, and the inversion tube filled to the desired inversion head as recommended by the liner supplier. The liner is restrained until the proper inversion head is reached by the workmen on the inversion platform and in the truck. The liner is then allowed to slowly report out of the inversion shoe and into the sewer itself. As it slowly enters the sewer, a thermocouple should be placed between the liner and the sewer pipe to measure temperatures in this location.

The supply valve on the water line must be carefully controlled to maintain the hydraulic head as the liner is allowed to slowly report out into the sewer. This process continues until the end of the liner is within approximately 10 feet (3 m) of the top of the inversion tube; at this point the inversion is halted. The liner is now half way into the sewer being lined.

A hold back rope is wrapped around the capstan at the top of the platform and attached to the end of the liner. This rope is used to control the rate of inversion by holding back the liner as it reports into the sewer. Should the liner be allowed to proceed unimpeded, it would very possibly report out at such a high speed that a constant water head in the inversion tube could not be maintained. Simultaneously with the connection of the hold back rope, a lay-flat hose is attached to carry heated water from the heat exchanger unit to the far end of the liner during the curing process. As the liner approaches the downstream manhole, a second thermocouple is placed between the liner and the sewer pipe wall.

Prior to commencing with the inversion process, a frame backstop should be installed in the far manhole to assure the stopping position of the liner. The liner is normally allowed to enter 6-15 inches (15-30 cm) into the far manhole before the inversion is terminated. This projection into the manhole allows the liner to expand and cause a slightly flared end at the sewer-wall intersection, thereby producing a superior seal between the sewer and the liner. At the completion of the inversion the hold back rope must be tied off to the capstan.

With the liner completely inverted, the next procedure is the curing of the thermo-setting resin saturated liner. The curing of the liner is accomplished by heating the water used to invert the liner to a temperature which will cause the resin to cure and harden. The temperature needed to cure the liner can be adjusted by the type and amount of catalyst added to the resin before wet-out, but in most cases 180°F (82°C) is used.

In most "Insituform" equipment the heat exchanger and recirculation pump are mounted in a truck which is backed up to a position adjacent to the inversion platform. This truck also contains a diesel-driven generator to power the electric drive motor on the recirculating pump, and to supply electricity for other lighting and power requirements. In addition to the generator, the truck has a boiler to supply heat for the heat exchanger. A suction line is attached from the inversion tube to the recirculating pump, with a second hose attaching the heat exchanger to the lay-flat hose.

As hot water circulation continues in the sewer, monitoring of the thermo-couple temperatures at the near and far manholes shows the actual increase in the temperature of the liner. The heat sink ability of the ground around a sewer can vary greatly with ground water, backfill and local utility conditions, and therefore the temperature of recirculating water versus liner outer surface temperature may vary considerably. Hence, the temperature of the circulating water should never be used as the only criteria for determining the extent to which the curing process has proceeded.

Basically the curing of the liner advances in four stages: (1) Initial heat-up to 160°F (71°C); (2) Exothermic reaction of resin commences at 160°F (71°C) and, along with continued recirculation of water, increases curing water temperature to 180°F (82°C); (3) Post-cure, when cure water temperature is maintained at 180°F (82°C) for several hours to ensure curing; and (4) Cool down, in which the cured liner is punctured allowing hot water to slowly drain out--this is replaced with cool water at the inversion tube. After the cool down is completed, the ends of the cured liner are cut in the manhole so as to assure the liner flaring at the manhole walls; this assures a seal.

The next step in the technique is the reinstatement of the services. This portion of the sewer relining technique is unique to the "Insituform" procedure. It requires the remote guidance of a cutter, called an "Insitucutter," operating within the sewer itself. The "Insitucutter" is similar to a pneumatic drill or router and is operated in conjunction with an internal inspection camera which faces the cutter.

The camera-cutter combination is pulled in tandem through the newly lined sewer in such a way that the camera continually views the cutter. The cutter is located adjacent to the location of each service which has been previously determined and recorded during internal inspections.

In addition to utilizing televising records of the previously recorded location of the services, they may also be detected visually on the interior of the newly lined pipe services appear as convex areas on the pipe wall. The operator responsible for cutting the service locations positions the "Insitucutter" by watching a television monitor; he also may place a microphone in the sewer for audio reference, since there is a distinctive difference in the sound levels noted between cutting the liner material and the actual conduit material.

The "Insitucutter" is capable of movement in six distinct directions. The operator, by both listening and watching the monitor, then proceeds to cut out the liner material covering the service opening. Excess resin in the liner migrates into the service joints and forms a sealed weld between the walls of the service pipe and the liner in the main.

Problems are created in the service reinstatement process when water stands in the service behind the liner. When the spinning drill pierces the "Insituform" covering over the service to be opened, water and liner material are splashed in every direction, including on the lens of the camera, signficantly impairing the view of the operator. Should the debris become heavy, the camera-cutter assembly must be withdrawn from the line for cleaning. This situation can cause a considerable slow down in the opening of services taps, and for this reason, all customers served by the sewer should be notified in advance that water will be shut off prior to rehabilitation. This alone may not totally relieve the situation since many times infiltration in the service line may backup behind the lining; service connections should therefore be cut out as soon as is feasible after the liner has cured. Insituform has now developed a shield on the cutter to prevent debris from splashing on the lense as well as an air exhaust aimed directly at the lateral to keep clippings away from the unit.

In smaller bore lines it has been noted that the "Insitucutter" drill cannot be moved into operating position if the service tap protrudes appreciably; in cases of this type the service must be exposed and reinstated in a conventional manner using excavation.

Experience has shown that the average service connection can be renewed by the "Insitucutter" in approximately 15-20 minutes. If there are many services to be renewed, it is presently the practice to travel the length of the lining and cut a small relief hole in each service dimple. This prohibits a build up of water from either infiltration or customer use of sanitary facilities. After all service connections have been relieved, the "Insitucutter" then commences to reinstate each service to full bore opening. This procedure in most cases relieves the requirement for providing any alternative sanitary facilities. Upon completion of the opening of the service connection, a post-Insituform internal Inspection is performed.

The "Insituform" installation team is generally supported with the following equipment: sewer cleaning equipment (high-pressure water jet), bucket machines, a twenty-six foot truck equipped with boiler/heat exchanger and circulating pump, a twenty-six foot materials truck and an internal inspection van.

The wet out crew is equipped with a semitrailer truck containing a three-tiered conveyor system and appurtenances for mixing and transferring the resin to the liner for felt saturation. In addition to the semitrailer truck, the wet out crew has tarps used to make sun shades so that all resin handling can be performed out of direct sunlight.

Method Limitations

Weather:

Test-and-Seal - As is the case with most forms of construction work, the testing and sealing with grout is severely hampered by cold weather. The viscosity of the separate components increases as the temperature decreases to such an extent that it becomes impossible to pump the liquids through the small bore hoses to the packer unit. Additionally the chemical reaction is adversely affected as the components become cold, thereby prohibitively increasing the gel time or stopping the gel process totally. Grouting contractors normally cease sealing operations as the temperature drops significantly below freezing.

Point Repairs - Utilizing the proper equipment, the excavation and replacement of line sections may be performed regardless of temperature; however, practicality dictates that when a substantial thickness of frost is in the ground, normal trenching techniques are no longer feasible and point repairs are no longer cost-efficient. Cold weather can also be a negative factor in the operation of machines and the productivity of human labor.

Precipitation can also be detrimental in the accomplishment of this type of sewer rehabilitation work. When attempting to perform work with heavy equipment in non-paved areas, many times the benefits accrued are substantially less than the damage done to the excavation area; extreme restoration costs in many cases encourage the contractor to discontinue work with heavy machinery in non-paved areas during wet weather periods. Sewer flows in sanitary systems which are susceptible to high infiltration and/or inflow may increase by such a degree as to render bypassing or plugging operations ineffective during or shortly after rainfall; therefore construction efforts requiring earthwork are discontinued during moderate to severe precipitation.

Conventional Polyethylene Sliplining - Any sewer rehabilitation process which is dependent upon some amount of excavation in its performance is basically effected in a similar manner as the point repair alternative. Conventional sliplining requires the construction of staging and receiving pits as well as the excavation of each service connection for reinstatement. These excavations, particularly those required for the staging pit, may be quite extensive, depending upon such factors as the sewer diameter and depth, the local soil conditions, ground water conditions, and at-grade considerations.

Cold weather tends to cause the joint fusion process to require more heat than normal, and makes the polyethylene slightly more brittle and more difficult with which to work; additional compensations must be allowed during the period following insertion to ensure that the liner has rebounded to its final length and diameter prior to cutting and sealing the ends and reconnecting service laterals, otherwise extreme thermal stresses could be imposed.

"Insituform" Lining - The primary weather parameter which might have an effect on an "Insituform" lining operation is that of cold temperature. As previously stated, the thermo-setting resin which is the heart of this concept requires circulated hot water to react, cure and harden. As the ambient temperature decreases, more energy is necessary to elevate the temperature of the recirculated water to a level desired to initiate the reaction. To ensure that the reaction has run its course and that the curing and hardening is complete, the curing flow must be recirculated for an extended period of time through the heat exchanger. Although cold weather is a negative factor in the installation of an "Insituform" liner, it in no way prohibits a successful project. As will be discussed later in this report, resin-impregnated liners have been stretched on the snow in Winnepeg, Canada, in 15°F (-26°C) weather prior to inversion; although the lining was not totally successful, the problems encountered were generally attributed to the inexperience of the contractor rather than the severe cold. Since excavation and surface restoration are not required in most applications, the weather limitations associated with these items are relatively unimportant.

Due to the requirements for scaffolding in this technique moderate to high winds severely impair progress.

In the majority of cases overpumping around the stretch to be rehabilitated is part of the "Insituform" method; therefore high sewer flows resulting from extraneous clear water contributions upstream may increase overpumping equipment for an inversion.

Sunlight or excessive heat may be damaging to the thermo-setting resin material, sunlight causing deterioration and heat initiating a premature chemical reaction. Care must be exercised to protect resin components from the elements.

Section Length:

Test-and-Seal - The test-and-seal operation is primarily suited to rehabilitate one manhole stretch at a time, with the grouting unit and remote winch assembly set up over the respective downstream and upstream manholes. However, it is possible to position the television/grout van some distance remote from the manhole section and, by the proper placement of appropriate pulleys and winches, to perform a satisfactory test-and-seal repair program; the method is implemented many times in the instance of rear property sewers.

The length of sewer which may be satisfactorily rehabilitated by this technique is dependent upon several variables: (1) the amount of hose and coaxial cable which the television/grout van has on its reels; (2) the ambient temperature affects the viscosity of gel components and indirectly determines how far the materials may be pumped through the packer supply hoses; (3) the performance characteristics of the pump and the diameter of the hoses also are factors in determining the distance to which material may be pumped; (4) the logistics of the field situation many times limits the length of pipe which may be rehabilitated by one set-up--the closer the upstream and downstream units can get to the sewer, the more cable and hose that are available for actual repair purposes; (5) larger sewers require a larger packer for grouting--this would somewhat restrict the length of sewer which might be repaired.

One grout van set-up at an intermediate manhole could, under very low flow conditions, be utilized to test and seal maximally two sections upstream and two downstream by only moving the remote winch and television/packer assembly and restringing the lines. Optimistically then approximately 1,200 feet (366 meters) could be rehabilitated by the test-and-seal technique using limited movement of equipment.

Point Repairs - This rehabilitation option really has unlimited potential as far as the length of section which may be rehabilitated is concerned, limited only by cost-effective and socio-environmental factors.

Conventional Polyethylene Sliplining - The length of sewer which may successfully be sliplined in a single pull using a high-density polyethlene liner depends upon such things as the capacity and weight of the winching unit, the diameter and depth of the sewer to be lined, the condition of the sewer to be lined, the logistical problems in the staging and winching areas, the liner pipe wall thickness required, the number and type of intermediate sewer structures. Discussions with liner manufacturers have indicated that in Glencoe, Illinois, a 14-inch (35.6 cm) diameter polyethylene liner of SDR 17 was pulled 3000 lineal feet (915 meters) through a deteriorated water main from a single excavation; obviously this footage would be somewhat reduced in a sanitary sewer, where there are many more defects in the interior of the conduit.

"Insituform" Lining - Theoretically the "Insituform" process of sewer relining should be unlimited with respect to the length of section which could be repaired in one inversion. Ancillary process considerations such as material handling, curing time, and overpumping requirements contribute to practicalities which generally limit liner inversions to approximately 1,000 feet (305 meters); however manufacturer information states that sections of up to 1700 feet (518.5 meters) in leength have been lined by a single inverion.

Spatial Requirements:

Test-and-Seal - Test-and-seal of sewer joint is performed most effectively by locating the equipment directly over the terminal manholes of the defective section. Only enough area is required to position the hydraulic cleaning unit at one end of the line and after the sewer has been cleaned and threaded to locate a television/grout van at the upstream manhole; a remote winch along with some downhole rollers is all that is generally necessary at the downstream manhole. The truck or van would require one lane of traffic approximately 30 feet (9.2 meters) long. The winch assembly demands only an area of 5 feet (1.5 meters) square.

Point Repairs - Spatial requirements for point repair work may vary significantly for each application, depending upon the size and depth of the sewer being repaired, what is done with the excess material, backfill specifications, flow bypassing requirements, soil and ground water conditions, appurtenant equipment required, and any state or local detouring standards; this option generally requires the investment of an area disproportionately large when compared to the amount of repair being done. In most cases, two lanes of roadway are lost (when sewer is located in roadway) basically for the entire length of the manhole stretch. Overhead clearance is required to accomodate the functions of the excavating equipment; generally the deeper the trench the more overhead area that is demanded by the operation.

Point repair rehabilitation methods in many instances cannot be considered due to the fact that extensive temporary damage to personal property would result from just gaining access to the site; point repairs on back lot lines many times become prohibitive because of private fences, landscaping, utility easements, swimming pools, or other structures.

Conventional Polyethylene Slipining - Not only is space required at the construction site for installation equipment, but additional areas are essential to store lining materials and excavated material as well as to construct staging areas for liner insertion. The equipment spatial demands are not outstanding; the basic units of construction are a high-powered truck-mounted winch, liner welding equipment, pipe handling equipment, a backhoe, and possibly a dump truck. Assuming on-site storage of excavated material is available and that flow bypassing is not necessary, the insertion operation would require at least one lane of roadway of 15 feet (4.6 meters) of non-paved area for a maximum distance of the manhole stretch plus the length of the staging trench plus an additional 30 feet (9.2 meters); should there be very little service reinstatement work intermediate between the liner ends, this area could be open for traffic.

The majority of spatial investment is necessitated by the staging trench and the liner surface staging area. The width of the insertion excavation must be sufficient to allow workmen to enter, with the length dependent upon the size and depth of the sewer and the bending radius of the sewer liner pipe, which is usually from 30 to 50 times the outside diameter of the liner pipe. In many cases where surface features are favorable, the surface staging area may approach the length of liner to be inserted; however should the area be limited, 38 foot (11.6 meter) sections of liner material can be butt-welded together as the insertion progresses--this is not ideal as it slows the lining process and also creates a stop-and-go lining procedure which applies added stress and strain in the liner and the equipment.

"Insituform" Lining - After the preliminary cleaning and televising work have been completed, the "Insituform" sewer lining alternative needs very little at-grade land to proceed. Assuming a remote wet-out site, the resin-impregnated liner is brought to the inversion platform by a panel truck; during this time of liner inversion, one lane of traffic would have to be detoured for approximately 40 feet (12.2 meters), or if overpumping is being performed, from the upstream pumping manhole to the bypass discharge manhole. Very seldom is more than one lane of roadway required in the "Insituform" method. During curing a semi-trailer truck is located adjacent to the inversion scaffolding; this unit contains the curing water circulation and heat exchanger equipment and is generally on site for 6 to 10 hours during the night hours. Since surface excavation is not normally required with the "Insituform" alternative, traffic need not be detoured over the entire length of the rehabilitation, but only around the equipment on the surface. After liner cure is completed, a small panel truck with closed circuit television capabilities commences to reinstate service lateral connections internally by means of the camera and "Insitucutter" assembly; again one lane of roadway must be detoured during this operation.

Flow Bypassing Requirements:

Test-and-Seal - As with most of the other types of sewer rehabilitation techniques considered herein, the requirement for bypassing flow around a section is directly dependent upon the amount of flow tributary to the line being rehabilitated. Since the packer unit is fabricated from a hollow metal cylinder, in most cases normal sewage flows can pass through the unit negating any need for bypassing.

Point Repairs - Overpumping is normally a requirement when performing point repair work, unless the flow in the sewer is negligible. Bypassing is relatively simple in that flow is pumped from a plugged manhole at the upstream end of the section to a manhole downstream of the point repair.

Conventional Polyethylene Sliplining - Normal sewage flow can usually be maintained during liner insertion through the annular space between the outside of the liner and the inside of the existing sewer.

"Insituform" Lining - Most "Insituform" inversions require not only total overpumping around the section to be rehabilitated, but also that water service to each sewer user connected to the stretch under repair be turned off to prevent backups behind the lined-over tap. Mainline overpumping generally consists of pumping from one manhole upstream of the lined section to one manhole below.

In most instances the sewer remains out of service for approximately 12 to 18 hours, depending usually upon the number of services in a line and the length of time required to reinstate each.

On-Grade Entry:

Test-and-Seal - Basically all manpower and major equipment required to perform grouting would remain at-grade, with no excavations necessary unless severely protruding taps, offset joints, etc. are encountered which cannot be passed with the television/packer assembly.

Point Repairs - Extensive excavation is necessary in this rehabilitation alternative; the sewer must be exposed to reveal the location and extent of the defective portions. The existing conduit must be removed and replaced with new by men and equipment in the trench and on the surface.

Conventional Polyethylene Sliplining - Although the majority of sliplining is performed at-grade, an appreciable amount of below grade work is necessary to prepare for as well as to complete the lining operation. A relatively large excavation is required to bring the polyethylene liner from the surface down to the elevation of the conduit to be repaired. To reconnect services after lining, each connection must be exposed by excavation and reinstated by men and equipment physically in the trench and at the surface; a sewer section with many services may require a great deal of surface disruption and subsequent restoration.

"Insituform" Lining - All "Insituform" work including service reinstatement, is performed either at-grade or within the conduit and therefore ideally does not require any excavation. This consideration is very important in applications where surface restoration costs are very high.

Root Procedures:

Test-and-Seal - Either mechanical or chemical measures should be utilized to clean root growth from all joints to be tested. Chemical treatment for root removal is recommended since it more thoroughly eliminates roots from joints and prevents their return by affecting the soil surrounding the pipe; however chemical root removal is quite time consuming and therefore may not normally be used. Many contractors combine a root inhibitor component in with the grout, which they use in conjunction with a mechanical root removal program; root ends which remain in the joint are encapsulated by the grout and prohibited from further growth by the root inhibitor. The effectiveness of the grouting is negated if the roots penetrate through the gel into the conduit.

Point Repairs - Root removal is not a critical factor in this type of repair.

Conventional Polyethylene Sliplining - Mechanical methods of root removal are necessary as a preliminary step to sliplining only when they are present to the extent that they will be a hindrance to the liner insertion.

"Insituform" Lining - An abundance of roots in a sewer to rehabilitated using "Insituform" may create masses of encapsulated organic material between the conduit wall and the cured liner; these masses not only adversely affect the hydraulic properties of the finished product but also may decompose behind the liner creating a gas void; in an extreme condition the uncured liner may be torn by a jagged root extending sufficiently into the sewer. For this reason total root removal should be performed prior to initiating lining work.

Safety:

General - All types of sewer rehabilitation have the common dangers associated with working in confined spaces, and proper safety precautions should be exercised.

Poisonous gases such as hydrogen sulfide, methane, carbon dioxide or ammonia may accumulate in manholes. Exposure to the gases can incapacitate or kill; an open flame or spark may cause an explosion of such gases.

The structure of a manhole may not be sound; wall materials may be deteriorated to the point where bricks can fall, or the manhole steps may be corroded to the degree that they cannot support any weight, or may be missing entirely. Objects may also be dropped or fall into a manhole, injuring workers.

Generally-accepted safety precautions should be observed while utilizing all types of sewer rehabilitation.

Test-and-Seal - Definite basic safety and handling precautions must be observed when using materials for the grouting process due to certain toxic properties of the ingredients and gel. Workers handling these chemicals, whether they be of the foam or gel type of grout, must wear rubber gloves, goggles and waterproof shoes.

Care also must be exercised when utilizing grout cleanup materials as many times these are toxic and flammable.

All sanitary sewer workers are exposed to the following types of hazards:

1. Physical injuries
2. Infections and infectious diseases
3. Oxygen deficient atmospheres
4. Toxic or suffocating gases or vapors
5. Explosive gas mixtures
6. Electrical shock

Appropriate safety precautions should be observed to minimize the possibility of danger from any of these items.

Point Repairs - General heavy construction safety standards as generated by OSHA should be observed during any type ot excavation work. Along with the typical hazards inherent with sewer systems work as described in the previous paragraph, there are the additional considerations of caving trenches, traffic, and injuries which might occur while working near heavy equipment and heavy unstable materials.

Conventional Polyethylene Sliplining - All the hazards noted for point repairs are prevalent in the sliplining technique, with the addition of several more. The winch cable in this alternative is exposed to extreme tension; should it snap or tear loose from the pulling head during insertion, damage and injuries could possibly be inflicted upon equipment or labor located close to the winching unit.

The polyehtylene pipe butt-fusion unit operates at a very high temperature of between 475°F and 500°F (246°C and 260°C), and naturally a degree of caution is necessitated by this heat.

The liner pipe to be inserted is stored in a staging area which, many times, is a roadway or easement location of considerable dimensions; there are pedetrian and vehicular traffic problems associated with this arrangement, as well as the possibility of tractive nuisance and related vandalism which may occur along unguarded stretches of the liner.

"Insituform" Lining - "Insituform" liners may be comprised of either polyester or epoxy resins; polyesther resin systems have as their components toxic, flammable substances which must be shown respect. The chemicals may be harmful if swallowed, absorbed through or contacted on the skin, or if inhaled.

To safeguard against these hazards certain precautions should be practiced by workers:

1. Avoid contact with eyes, skin, clothing--wear protective gloves, apron and goggles.
2. Avoid breathing--wear respirator or dust mask.
3. Use adequate ventilation (600 cfm blower).
4. Keep containers closed when not in use.
5. Wash thoroughly after handling.
6. Do not bring sources of ignition near chemicals.

During "Insituform" curing, styrene vapors, which in certain concentrations may be extremely flammable, escape to the atmosphere; these are very irritating to the eyes and skin, and therefore continuous ventilation should be provided and smoking should not be allowed in the vicinity. Hot water utilized to initiate the thermo-setting reaction can be dangerous; workers should wear protective clothing during the curing phase, and shrouds should be placed on and around the inversion platform to ensure that anyone coming near the structure will not be subjected to the materials.

Contractor scaffolding used in the inversion procedure is always a safety concern. The construction of this scaffolding should be based upon a stable and level foundation, and the structure carefully fabricated with quality materials. Railings and baseboards should be included to ensure that men or equipment do not fall from the structure. Hard hats should be worn at all times.

It has been past practice to manually reinstate service connections in sewers of 18 inch (47.7cm) diameter and greater, by pulling a laborer with a pneumatic saw through the line on a fabricated sled; generally while the man is cutting out services, sewer flow is being bypassed around the lined section. Emergency precautions should be considered to take into account the remote possibility of losing the upstream sewer plug, which would allow the backed-up flow to surcharge the lined section possibly drowning or washing away the workman. Self-contained underwater breathing apparatus should be provided the worker along with appropriate safety lines. Positive ventilation (blowers) should be a fundamental piece of equipment at each "Insituform" lining site.

Remote Plant:

Test-and-Seal - As previously noted a test-and-seal rig need not be directly over the terminal manhole of the sewer being rehabilitated. In many cases the van may be parked on the street with the access manhole on the rear lot line; the hoses and cables are then stretched overland to the manhole and down into the sewer stretch. The distance which the van may be positioned from the manhole is basically dependent upon the lengths of hose and cable carried by the van.

Point Repair - A remote location of equipment is really not applicable in this situation.

Conventional Polyethylene Sliplining - In areas where access to the sewer to be lined is difficult but where other insertion factors are favorable, the winch unit may be set up somewhat remote from the terminal manhole; a sophisticated roller arrangement may be required to facilitate this installation procedure. Extreme precautions must be exercised during this type of operation due to the significant forces which are inherent with the pulling operation.

On relatively straight sewer runs it would be feasible to position the staging pit one or two manholes distant from the section to be lined; all sewer sections through which the liner must be drawn must be inspected internally to verify that these stretches are in a condition which would enable the liner to pass without problem.

"Insituform" Lining - A number of "Insituform" inversions have been successfully completed with water supply, wet-out and curing equipment stationed remote from the site; in fact, in most cases the wet-out trailers are situated at a central location with the resin-impregnated liners transported to each site in the project as they are needed. Should access to a site be unattainable to the liner transport and boiler vans, a remote inversion is required. The liner may be trucked to the site using a four-wheel drive vehicle, or as has been done in some cases, carried to the inversion platform by hand. The water supply can be transmitted to the area by high-pressure hoses or, if necessary, by tanker trucks.

After inversion the resin may be cured by recirculating the inversion water to remotely-located boiler units; depending upon such factors as the size of pipe, the distance from the boiler unit to the inversion location, the weather, etc.; one boiler or more boilers in series may be required.

Time:

Test-and-Seal - As with the other alternatives the time to accomplish rehabilitation by this means is dependent upon numerous variables, such as sewer diameter and length, the number and degree of defective joints, the type of embedment material, the weather, sewer flow, optimum gel time used, the type of test required, etc. A moderately defective joint in a relatively small bore line can be tested, sealed and retested in less than two minutes; a typical stretch of 350 feet (106.7m) of 8-inch (20.3cm) pipe in 3 foot (.9m) sections could be tested and sealed in less than four hours, not including set-up time, even if it were assumed that 100 percent of the joints failed the initial pressure test.

On 8-inch (20.3 cm) sewers in Hagerstown there was a wide range of times required for test-and-seal operations due to the factors previously described, as well as some equipment problems. In one case it required 24 hours to test-and-seal a 235-foot (72 m) stretch of eight-inch (20.3 cm) sewer with 39 failed joints, while the best performance for this size sewer was testing and grouting 250 feet (77 m) of conduit with 67 failed joints in three and one-half hours; the optimum performance translates to handling a joint every 2-1/2 minutes.

With larger diameter lines the average time per joint generally increased: (1) 6.3 minutes for 10" (25.4 cm); (2) 9.3 minutes for 12" (30.5 cm); (3) 7.2 minutes for 15" (38.1 cm); (4) 11.5 minutes for 18" (45.7 cm); (5) 6.4 minutes for 21" (53.3); and (6) 13.5 minutes for 24" (61.0 cm). In many of the larger bore lines and some smaller diameter sewers in Hagerstown, the contractor was unable to successfully seal the joints as evidenced by some extremely long sealing times; "Insituform", where cost-effective, was utilized in its place and was successful in reducing infiltration where used.

Point Repairs - Under optimal conditions, where minimal bypassing is required and where the sewer is not excessively deep and has easy access, a point repair crew may complete an average of two 16-foot (4.9m) long pipe replacements, including backfill, per day; maximum production might run as high as four repairs per day. These completion rates do not include surface restoration work, which may significantly extend the time required.

Conventional Polyethylene Sliplining - The vast majority of time required to slipline a sewer is invested in the preliminary preparation work performed prior to the actual insertion, i.e., staging pit construction, liner staging, butt fusion, traffic control, etc.; additionally the excavation and reconnection of service laterals is a time consuming job. To slipline a 400 foot (121.9 m) section of sewer would probably require a minimum of one day on-site preparation, some four hours to draw the liner through the sewer, and approximately two to three hours to reinstate each service, excluding restoration work.

"In the LaGrange Highlands conventional sliplining project, the preparatory staging, excavation aand equipment placement required one day of work. The actual pulling of the polyethylene liner into position necessitated another two days. In excavating to expose service connections the excavator crushed a section of mainline, necessitating the relocation of the winch and two separate pulling operations. The stretched liner was allowed to rebound to its original length and diameter over night; the fourth day all services were reconnected, backfilled and rought graded. Since the service excavations were made in the roadside ditches, the disturbed area has to be landscaped; this operation took an additional several weeks."

"Insituform" Lining - Preliminary work in the "Insituform" procedure generally commenced in the afternoon of the day of lining. The sewer section is cleaned and televised and from this internal inspection, an assessment is made regarding any further operations required prior to lining. As this televising proceeds, a second crew begins the fabrication of the inversion plaform scaffolding. When the internal inspection crew determines that the sewer is in a condition suitable for inversion, a third team at the wet-out site begins to cut the liner to the proper length, seal the ends and fill the liner with the promoted resin material. When all the preliminary tasks have been completed and when it has been determined that flows are in a range which can be tolerated, overpumping is initiated and the inversion is started. From start to finish of the actual inversion phase of lining a typical manhole section took in the neighborhood of two (2) hours in Hagerstown, with the majority of the sewers being 18 inch (47.7cm) diameter and greater. The amount of time required for curing water circulation may vary from 4 to 8 hours depending upon such variables as the size and length of line, the weather conditions, the boiler capacity, ground water conditions, resin material, etc. Service reinstatement in Hagerstown typically took from 15 to 30 minutes, with much of the reinstatement performed manually by dragging a man on a sled through the lined sewer. Lines in most cases were out of service for 16 to 18 hours.

Public Relations:

Test-and-Seal - In that this technique requires no excavation and, in the majority of cases, no service disruption. The related public relations impact for this alternative is minimal. Some concern is shown by residents when remote work is performed in front or rear yard locations due to cables and hoses being stretched across landscaped areas, but this concern is generally unfounded since the process causes very little damage. Work in roadways generally closes off one lane of traffic; since a typical sewer section may be tested and sealed in several hours, the related traffic disruption is relatively inconsequential.

Point Repairs - Point Repair work is comprised chiefly of excavation, which inherently is difficult for many residents to accept. Associated with point repairs are road closures, line bypassing, construction noises, and surface damage and restoration, all of which are potential public relations nightmares. Although the actual point repair may require less than a day to complete, the construction scars may last for many months until final pavement restoration is complete or until sod is placed and starts to take hold. People have a real aversion to anyone digging holes on their property, and prior to performing any private property point repairs the resident should be appraised of the circumstances necessitating the work and the problems which might ensue should the repair be postponed or cancelled; it is much easier to obtain cooperation in advance than after the fact.

Conventional Polyethylene Sliplining - This procedure experiences all of the public relations problems of point repairs plus those associated with staging a sliplining project. In the case where the entire length of liner must be laid out and fused prior to drawing it into the sewer, many logistical problems may be encountered. The liner may have to lay across lawns, driveways, and roadways, creating access and transportation problems.

"Insituform" Lining - Generally the major public relations concern connected with "Insituform" is the termination of user service in that particular section from the time of inversion until that time when the connection is reinstated. Residents must be informed that they may not use water for a period of from 12 to 15 hours minimally during the rehabilitation. A further source of public irritation results from the occasional practice of inverting and curing the liner during the sleeping hours. Noise from the water circulating and heating equipment and disturbances caused by artificial lighting requirements tend to be disruptive in residential neighborhoods, but are only present for one night; Hagerstown officials report that no noise complaints were received during the "Insituform" construction where specifically requested normal practice is during day. It is a typical practice to invert and use during daylight hours.

Final Product Characteristics:

Test-and-Seal - Test-and-seal methods were used to repair joints which were pulled apart or offset and radial cracks over which the packer unit could straddle. Longitudinal cracks, broken pipes, etc. could not be rehabilitated in this fashion, and indeed could be further deteriorated by the forces employed in the test-and-seal technique. Structurally, a pipe section must be in relatively good shape, with barrel sections basically intact, for success of the repair. In the Hagerstown sewer system rehabilitation project an acrylamide gel was used to form a flexible seal on the pipe joint exterior. When the gelation of the chemical grout is complete, an impervious mass of sealant acts as a donut around the joint, effectively sealing out ground water; the surrounding backfill is saturated and stabilized, thereby enhancing the integrity of the joint or radial crack.

The success of acrylamide grouts is strongly dependent upon the soil and ground water conditions. Grout is not adversely affected by the presence of ground water, although a certain amount of dilution occurs. In sandy type backfill soils, the grout will displace the ground water; in clay soils with very low permeability the grout may not function since it cannot stabilize the soil. Many of the sewers grouted in Hagerstown were cut into limestone bedrock which, due to crevicing, was susceptible to wide fluctuations in ground water level. When the ground water is over the grout, some dilution may render the grout only marginally effective; in low ground water conditions, admixtures and fillers were added to the gel to reduce the shrinkage which occurs under prolonged dry conditions. The intermittent wet and dry cycles in this geology led to significant problems with the sealing process. In many cases, where large separations in joints or wide radial cracks were present, the contractor would pump excessive amounts of grout material without being able to seal the defect-the void which formed over time as the backfill material washed into the conduit was too extensive to allow for cost-effective grouting to take place.

In other applications, the ground water would rise and recede so quickly after precipitation that the grout material would be stripped from the cracks or joint leaving it in a pre-repair state; other methods of rehabilitation were used effectively to remedy this situation.

It may be concluded that the acrylamide grout is an effective method of sealing leaks in pipe joints when conditions are favorable and proper methods are implemented. The seal is highly flexible and can accept a reasonable degree of movement. The durability and service life of the product has been questioned in the past, but field data assembled in this report do not support this concern.

Point Repairs - As previously reported, point repairs and manhole repairs in the Hagerstown project were performed by city staff, with satisfactory results. Chiefly this alternative was utilized to repair badly cracked, broken, crushed or collapsed pipe, or cross-section protrusions where other options are not feasible or cost-effective; generally speaking, one basic criteria for the selection of this technique is that the problem area be very localized and easy to identify and isolate. Excavation and replacement naturally has the longest track record of the alternatives considered, with an abundance of local contractors capable of performing the work. In most applications point repairs are used in conjunction with other available techniques, either as a preliminary step to facilitate the use of other repair steps or as a complementary task designed to contribute in the reduction of clear water flows. Many times in grouting or lining, protrusions or offsets must be corrected to allow for the clearance necessary for each technique to proceed. In Hagerstown, numerous lines received point repairs prior to test-and-seal work, with the overall effectiveness in I/I reduction shown in a later section of this report.

Point repairs are extremely effective in accomplishing their function within the repair proper; this is to say, infiltration is eliminated where new pipe with state-of-the-art joints is installed. Migration of ground water along the trench to sections of older pipe or manholes which are vulnerable to seepage may allow for recurrence of clear water entrance through new locations.

Excavation and replacement does provide long lasting materials designed to meet current standards, as well as giving the highest strength repair available.

Conventional Polyethylene Sliplining - Polyethylene liner pipe and fittings are relatively lightweight and high strength, with considerable flexibility and heat fusibility; the liner is made of a high-density, high-molecular weight polyethylene. Physcial properties of the material are as follows:

1. Tensile Strength at Yield, 73°F	3200 PSI
2. Modulus of Elasticity	30,000 PSI
3. Flexural Modulus, 73°F	120,000 PSI
4. Ultimate Elongation, 73°F	>700 %
5. Long-term Hydrostatic Strength, 73°F	>1450 PSI
6. Environmental Stress Crack Resistance	>1000 Hrs.
7. Impact Brittleness Temperature	<-180° F
8. Thermal Expansion Coefficient (in/in °F)	
15-85°F	7.2×10^{-5}
85-150°F	8.3×10^{-5}
150-200°F	9.5×10^{-5}

Polyethylene piping has corrosion resistance to most acids, caustics, salt solutions and other corrosive liquids and gases; the pipe will not scale, pit or rot and will not corrode electrolytically or galvanically. The in-place liner provides an extremely smooth surface which is very resistant to abrasion and will not support bacterial growth. The flexibility and resiliency of the liner enables it to absorb typical earth movements without cracking.

The sewer section proposed for sliplining repair should be internally inspected and reviewed in detail prior to the actual drawing of the liner through the conduit so that all defects within the sewer which might obstruct the liner might be repaired in advance. Extreme damage could be done to an existing sewer should the liner become hung-up on an offset, break or protrusion because the forces associated with this method are very great.

Due to the fact that the liner has an outside diameter somewhat less than the inside diameter of the sewer, the cross-sectional area for flow is reduced from that of the original sewer. In larger diameter applications, this reduction in the hydraulic cross-section is more than offset by the increased smoothness of the liner, thereby resulting in an increased flow capacity for the lined section; generally in small-bore lines, there is some reduction in capacity after lining. The annular space between liner and parent pipe, unless grouted at manholes, services, missing pipe, etc. can act to convey clear water, thereby reducing the technique effectiveness; these areas should be grouted.

Properly designed polyethylene liners are capable of withstanding the imposed forces of external hydrostatic pressure created by ground water and earth loadings caused by backfill and surface loads.

As can be seen in more detail later in this paper, conventional polyethylene sliplining properly installed with the services and terminals grouted in place is extremely effective in eliminating infiltration and root intrusion totally from the mainline being repaired. Strong consideration should be given to the simultaneous rehabilitation of defective manholes and services adjacent to the lined stretch in order to prevent ground water from migrating along the sewer trench to enter the system as infiltration in these deficient areas.

"Insituform" Lining - "Insituform" when cured is a smooth impermeable, corrosion resistant new pipe within the deteriorated conduit; the structural integrity of a damaged pipe section may be significantly enhanced by the placement of an "Insituform" liner. Cured "Insituform" using a polyester resin has the following physical properties:

1. Tensile Strength	3,000 PSI
2. Modulus of Elasticity	300,000 PSI
3. Shear Strength	8,150 PSI
4. Flexural Strength	3,000 PSI
5. Flexural Modulus	300,000 PSI
6. Deformation under Load	0.149 PSI
7. Coefficient of Expansion, in/in/°C	5.96×10^{-5}
8. Deflection Temperature, °C @ 66 psi	106°C
9. Deflection Temperature, °C @ 264 psi	92.5°C
10. Fatigue Endurance Limit, @ 10^7 cycles	1360 PSI
11. Compressive Strength	15,500 PSI
12. Compressive Modulus	325,000 PSI
13. Bearing Strength @ 4% Deformation	3330 PSI
14. Bearing Strength @ Maximum	5910 PSI

The liner, being relatively thin and fitted somewhat tightly to the wall, only minimally reduces the hydraulic cross-section of the original conduit; this fact, coupled with the smoothness of the finished product, generally acts to significantly improve the flow characteristics of the rehabilitated section. Not all data collected in this study bears out this increased capacity claim. "Insituform" successfully prevents the infiltration/exfiltration of ground water in the defective section; it halts the infiltation of backfill materials into the sewer, which, over time, may undermine the pipe causing a surface collapse. Roots may not penetrate the liner, and due to its smoothness debris tends not to collect in the pipe. Interviews with "Insituform" clients indicate that widely accepted sewer maintenance techniques, such as high-pressure flushing and power rodding, have no appreciable adverse effects upon the liner materials. A more quantitative analysis of "Insituform" properties will be pursued in the following sections.

Before and After Sewer Conditions:

The macroscopic picture of the success of a sanitary sewer system rehabilitation program, including the variety of repair techniques implimented, is documented by the flowmetering data at the wastewater treatment facility. Prior to the collection system rehabilitation project (1974) Daily Average Flows at the treatment plant for the year were at 7.62 MGD (28,200 M^3/Day); Wet Weather Flows would approach or exceed 20.0 MGD (74,000 M ^{3}/Day) in a 2.0 inch (5.1 cm) rainfall event. Flow data collected for the calendar year 1981, after sewer rehabilitation was completed, showed a Daily Average Flow of 4.29 MGD (15,900 M ^{3}/Day); a 2.0 inch (5.1 cm) precipitation in 1981 produced a maximum Wet Weather Flow of 7.3 MGD (27,000 M ^{3}/Day). These values represent an impressive 43 percent DAF improvement and a 63.5 percent improvement in peak flows as a result of the comprehensive sewer rehabilitation project.

Test-and-Seal and Point Repairs - In order to get good representative data, this survey considered sections which received either test-and-seal rehabilitation or both test-and-seal and point repair rehabilitation techniques. Flowmetering for these sections was initially to be performed before-and-after rehabilitation using the automatic flowmetering systems provided by the ADS Company, as previously described; however after reviewing the computerized data received, it was determined that representative conclusions regarding infiltration values could only be ascertained by comparing original flowmetering performed during the Sewer System Evaluation Survey with field metering performed by the consultant staff after rehabilitation was complete. The city staff assisted the consultant in selecting revised test sections which were not only in areas of high ground water, but were also relatively easy to isolate without creating significant problems within the the upstream collection system. The upstream manhole was plugged and a 90° V-notch weir inserted in the inlet pipe to the downstream manhole; readings were monitored until such a time when flow stabilized, and these values were assumed to represent infiltration at that time. Although the groundwater level could not be established accurately, manhole seepage indicated it to be over the crown of the sewer pipe in every case checked. Before-and-after infiltration quantities are presented in Table 1 on the following page of this report.

Recent interviews with City staff have indicated partial to total failure of grout in numerous sections since flow monitoring was performed.

TABLE-1 TEST-AND-SEAL/POINT REPAIR INFILTRATIONS

SECTION (MH.-MH.)	LENGTH FEET (M)	DIAMETER INCHES (CM)	GROUNDWATER ABOVE PIPE CROWN FEET (M)	REPAIR METHOD	PRE-REHAB. INFILTRATION[1] G.P.D. (M. 3/DAY)	POST-REHAB INFILTRATION G.P.D. (M. 3/DAY)	REDUCTION IN INFILTRATION G.P.D. (M. 3/DAY)	COST OF REPAIR	COST PER G.P.D. ELIMINATED
16-34 16-33	400 (122.7)	8 (20.3)	3 (0.9)	PT. REP./GRT.	161,280 (610)	50 (0.2)	161,230 (609.8)	$2561.47	$ 0.02
16-31 16-36	350 (107.4)	8 (20.3)	4.5 (1.3)	PT. REP./GRT.	7,200 (27.2)	2100 (7.9)	5,100 (19.3)	$ 1758.24	$ 0.34
16-36 16-37	308 (94.5)	8 (20.3)	5 (1.5)	GRT.	36,000 (136)	1275 (4.8)	34,725 (131.2)	$ 538.55	$ 0.02
16-22 16-23	378 (116)	8 (20.3)	2 (0.6)	GRT.	53,200 (201)	8100 (30.6)	45,100 (170.4)	$ 766.91	$ 0.02
16-8 16-9	300 (92)	8 (20.3)	1 (0.3)	GRT	10,080 (38.1)	400 (1.5)	9,680 (36.6)	$ 577.46	$ 0.06
16-8 16-7	300 (92)	8 (20.3)	1 (0.3)	PT. REP.	1,440 (5.4)	175 (0.70)	1,265 (4.7)	$ 1049.33	$ 0.83
22-27 22-25	301 (92)	8 (20.3)	1 (0.3)	PT. REP./GRT.	4,320 (16.3)	1220 (4.6)	3,100 (11.7)	$1532.45	$ 0.49
4-79 4-78	275 (84)	8 (20.3)	1.5 (0.5)	PT. REP./GRT.	14,400 (54)	410 (1.5)	13,990 (52.5)	$ 1615.34	$ 0.12
2-46 2-48	400 (122.7)	8 (20.3)	1 (0.3)	GRT.	41,040 (155)	3750 (14.2)	37,290 (140.8)	$ 2175.68	$ 0.08
2-52 2-51	300 (92)	8 (20.3)	1.5 (0.5)	GRT.	14,400 (54)	764 (2.9)	13,636 (51.1)	$ 1867.04	$ 0.21
								AVERAGE	$ 0.21

1. VALUES TAKEN FROM CITY OF HAGERSTON "SEWER SYSTEM EVALUATION SURVEY", BUCHART--HORN, CONSULTING ENGINEERS.

These sections were tested some three years after the point repairs and sealing operations were completed and in locations where the groundwater was significantly over the crown of the pipe. Without exceptions, these rehabilitation methods were very successful in the test sections studied, with an average elimination of infiltration calculated to be 94.7 percent at an average cost of $ 0.21 per gallon of infiltration eliminated daily. According to the Sewer System Evaluation Survey for Hagerstown prepared by Buchart-Horn, Consulting Engineers, the present worth cost to treat this infiltration would be $0.646/G.P.D.; it can therefore be seen that the point repair and test-and-seal combination of rehabilitation procedures was extremely cost-effective in this situation, with sections where only test-and-seal was utilized the most economical application.

Some concern has been generated in the past regarding the durability of the grouting method product. As previously stated, this interest was justified in applications were there was considerable fluctuation in the ground water table, creating a cyclical wet and dry environment for the sealant. According to sources within the Hagerstown Water Pollution Control Department, numerous sections of this nature were unsuccessfully attempted to be sealed during this and previous collection system rehabilitation programs; failure of the seal necessitated the use of other methods to repair the section.

Precautions should be exercised in applications where the sewer is located in creviced bedrock or very permeable material in which ground water levels vary rapidly and/or significantly,; it may be wise to perform backfill soundings to establish the extent and location of trench voids that may act to neutralize this procedure.

As with all sewer rehabilitation techniques, this work should be perfomed on an area-wide basis, to include manhole and service repair in order to ensure that the migration of ground water does not act to simply relocate the infiltration to other points of system weakness.

Under the proper conditions of relatively constant trench moisture and the existence of backfill material compatible with the grout, this method seems very effective in reducing infiltration, and at least over the three years which this study spanned, the material was very durable.

The test-and-seal rehabilitation contributes nothing to the structural integrity of the in-place conduit; however, it does act to prevent trench backfill material from entering the sewer, thus creating backfill voids and increased loading on the pipe. Additionally the grout does not change the flow characteristics of the pipe repaired; the capacities and velocities realized prior to rehabilitation will be basically the same as those noted after.

Point repairs were performed in advance of test-and-seal procedures on the Hagerstown project by city staff. Crushed and broken pipe was removed and replaced when it was determined to be cost-effective, or when it was necessary in order to get television and grouting equipment through the line; also pipe sections having longitudinal cracks which could not be repaired by grouting, were replaced when cost-effective. The installation of a new section (or sections) of pipe with state-of-the-art joints gives a very durable, watertight stretch with may be expected to last almost indefinitely if properly installed, backfilled and maintained; in conjunction with sealing an effective means of eliminating excessive infiltration can be achieved. Obviously in the case of replacement of crushed or broken conduit, the localized flow properties are vastly improved, with an increased cross-sectional area and a reduced Manning roughness coefficient; improvements in section flow characteristics could not be tested due the inaccessibility of the repairs. Dependent upon the location and the extent of the point repair and the amount of flow in the sewer, variations of flow control had to be employed, for this method, with overpumping utilized most frequently.

Conventional Polyethylene Sliplining - Preliminary field studies of problem areas in the LaGrange Highlands Illinois sanitary sewer system revealed that the average slope of the sewer between manholes was adequate, but for some reason wastewater flow was being restricted within the conduit. Internal inspection by closed-circuit television showed a significant root intrusion, badly offset and pulled joints, as well as cracked and broken pipe; structurally the pipe was in very poor condition. The sewer sections were in areas of normally high ground water. Line rehabilitation by high-pressure flushing and root cutting proved ineffective; infiltration through joints remained extremely heavy, with the problem being compounded by the location of the sewer directly under a roadside drainage ditch.

The LaGrange Sanitary District decided the condition of several sewer stretches warranted extensive rehabilitation by the conventional sliplining technique; hydraulic calculations suggested that anticipated loading could be conveyed by the polyethylene liner without overload. Approximately 780 lineal feet (239 m) of 12-inch (30.5 cm) diameter vitrified clay sewer was lined in two stretches between Manholes 209 and 211 during August of 1980; there were a total of three (3) 6-inch (15.2 cm) service connections which had to be reinstated by means of excavation after lining was completed. Note that only the downstream section from MH 209 to MH 210 was analyzed due to surcharging dangers associated with the upstream section.

A 22-foot long by 8-foot wide x 10-foot deep (6.7 m x 2.4 m x 3.1 m) insertion pit was located at the downstream manhole (M.H. 209) and a 10-inch (25.4 cm) I.D. high-density polyethylene liner (S.D.R. 29.5) winched in from the upstream manhole using an open steel pulling head. Due to a collapsed section of vitrified clay pipe, the liner had to be drawn into the sewer from two directions and clamped at the joint with a mechanical sleeve. Although it was not anticipated that flow bypassing would be required, the pipe collapse necessitated overpumping until the condition was remedied. The mainline was never out of service; the services were allowed to flow into the annular space between the clay pipe and the liner, and thus were always active. One obvious drawback which was evidenced by this project is the problems associated with the stretching of the material during insertion, and the subsequent shrinkage after the stresses are removed; the liner must be allowed from 12 to 24 hours after insertion to stabilize at final dimensions, at which time services can be reconnected and the annular space can be grouted at the manholes.

Services were reinstated in this instance using strapped P.V.C. saddles and mission couplings to the liner pipe. The annulus at each manhhole was filled using oakum saturated with a chemical grout material; this prohibits the clear water in the annular space from entering the collection system at the manhole doghouse area.

Structural - Polyethylene liner pipe is flexible and therefore under an earth load derives the vast majority of its structural strength from the lateral support provided by backfill soil or by direct contact with the lined conduit or any fill material within the annular space. In cases where the entire parent pipe is missing, the strength of the polyethylene pipe is very dependent upon the type of material surrounding the liner. Complete contact of backfill with the pipe is best attained with granular material backfill; with proper backfill optimal strength may be developed with support capabilities in the neighborhood of 2000 pounds per lineal foot (2982 kg/m) at 5 percent deflection achieved. If soils of a cohesive type (clays) surround the liner, complete contact may not be attained, with a resultant strength value of approximately 820 pounds per lineal foot attainable. For this reason, when earth and traffic loadings on a sewer section are expected to be high, granular backfill should be placed around the liner in areas where parent pipe is damaged or not present. In applications where heavy loadings are anticipated and the parent pipe is badly deteriorated, strong consideration should be given to filling the annulus with non-shrinking grout material; this material will act to provide lateral support to the polyethylene liner.

A follow-up internal inspection of the test section performed several months after the liner installation showed no deterioration of the material in the main line; some very minor leakage was detected coming from services, attributed to poor joints and pipes within private property.

Infiltration - In an effort to determine the effectiveness of the conventional sliplining technique upon infiltration sources, the following methods of study were implimented.

To obtain infiltration values in the parent pipe, the upstream manhole (M.H. 210) was plugged and a 22-1/2-degree V-notch weir installed in the downstream manhole (M.H. 209); also services in the stretch were not active during metering. After the flow over the weir stabilized, flow measurements were taken at the intervals shown in Table 2, with the average pre-lining infiltration being approximately 9620 gallons daily (36.5 M^3/D) (Table 2). The ground water in this section was not measured, but evidence showed it to be approximately at the pipe crown during this analysis.

TABLE 2 WEIR ANALYSIS OF INFILTRATION (LA GRANGE HIGHLANDS)

STRETCH MH 210 - MH 209 PRE-LINING (July 30, 1980)		POST-LINING (August 27, 1980*)	
TIME	INFILTRATION BY WEIR GPD (M^3/D)	TIME	INFILTRATION BY WEIR GPD (M^3/D)
1:16 p.m.	6840 (26)	12:01 p.m.	2880 (11)
1:23 p.m.	9620 (37)	12:07 p.m.	1760 (7)
1:30 p.m.	9620 (37)	12:15 p.m.	1520 (6)
1:37 p.m.	9620 (37)	12:23 p.m.	1520 (6)
Ground water above crown	At crown level	Slightly below crown level	

* Tested prior to grouting of annular ring.

After this test section was lined, similar procedures to those described in the previous paragraph were used in developing, a post-sliplining value of infiltration within the section. A small trickle was noted over the weir during the second battery of tests, with the clear water contribution estimated at 1520 GPD. Since the service connections at this time had been reconnected but the annulus had not yet been grouted it was deduced that the infiltration noted was coming from service and mainline infiltration traveling along the annular space and pipe entrance and exit areas of Manhole 209; visual inspection after the annular space was filled showed a marked reduction in clear water flow.

Using the conservative post-repair infiltration value for the section of 1520 GPD, direct subtraction gives a figure for infiltration eliminated of 8100 GPD. Cost data provided by the LaGrange Highlands Sanitary District showed that the total 780 foot (239m) section which was lined amounted to a total price of $14,857; this number includes $660 for initial internal inspection and approximately $1800 for service reinstatement and restoration. The data reduces to a cost per infiltration eliminated value of $1.85 per GPD. This would not be considered a cost-effective technique in Hagerstown at this rate, but was indeed a matter of necessity in the LaGrange system; since neither State nor Federal funding was involved, a comprehensive cost-effective analysis was not performed by the LaGrange S. D. consultant for this application. The consultant indicated that the infiltration tests performed as part of this report were probably on the low side. During rainfall events, when storm water is flowing in the roadside ditches, the very permeable soil allows water to seep rapidly through the trench material, and to quickly infiltrate the deteriorated conduit; this almost-immediate response of flow to precipitation would generally give rise to the theory of an inflow source causing the problems--however, according to the LaGrange consultant, previous testing indicates that this is not valid.

Since infiltration tests were not run during or directly following a significant rainfall, it was felt by the consultant that the pre-lining data was probably a factor of ten or more below that which was representative under extreme conditions for the site; if this were the case, the cost-effective values shown above for this technique would have been greatly enhanced.

Flow Characteristics - As part of this study, flow characteristics of the sewer prior to and after lining were determined; Manning's roughness coefficient (n) was calculated initially for the deteriorated test sections, and then recalculated after the sections were rehabilitated to establish the improved smoothness of the bore. The testing procedure utilized the Manning Equation as defined below:

$$Q = A \frac{1.486}{n} S^{1/2} R_h^{2/3}, \text{ Where}$$

Q represents the rate of discharge measured in cubic feet per second, a known quantity in this test.

A is the area of the wetted cross-section of the pipe measured in square feet, a measured quantity in this case.

n is a coefficient which is used as a measure of the interior surface roughness of a pipe, known as Manning roughness coefficient, and was determined by this analysis.

S represents the slope of the energy gradient of the line, which in this case was assumed to be the same as the slope of the conduit measured in feet of drop per running foot of pipe. Parameters to determine this were measured in the field.

R is the hydraulic radius of the wetted cross-section of pipe, arrived at by dividing the wetted cross-sectional area of the flow by the wetted perimeter of the pipe.

For the purposes of comparision of "n" coefficients, the following method was implimented to give representative values for the parameter.

Prior to and after lining the test section, the sewage flow was plugged upstream of the test segment. Known quantities of water from the public water system varying in discharge from 69 to 129 GPM (.35-.49 M3/Min.) were then metered separately by means of a recently-calibrated 2.44 in. (6.2 cm.) Hersey-Sparling hydrant meter into each test section, and the depth of flow measured with a thin stainless steel scale at two-minute intervals in the downstream manhole (MH 209). The flow introduced into each segment was increased half way through the test to determine the effect of higher flow on the roughness coefficient "n". The results obtained from the flow properties test are displayed in Table 3. Reduction of the raw field data resulted in the following values for roughness coefficient of the test section both before-and-after lining:

TABLE 3. MANNING ROUGHNESS COEFFICIENT

	Slope %	Test Flow GPM(M3/Min.	Average Flow Depth in.(cm.)	Calculated "n"
Pre-Lining Stretch				
M.H. 209- M.H. 210	.50	69 (.26) 113 (.42)	3.08 (7.82) 3.56 (9.04)	0.0302 0.0274
			Ave.	0.0288
Post-Lining Stretch				
M.H. 209- M.H. 210	.50	124 (.46) 129 (.49)	2.63 (6.68) 2.72 (6.91)	0.0107 0.0104
			Ave.	0.0106

The pre-lining values obtained for "n" in this analysis appear to be relatively high, most likely due to some turbulence at the inlet to the monitoring manhole caused by cracked and broken pipe. For comparison purposes pre-lining roughness for the in-place vitrified clay pipe is assumed to be "n" = 0.020; the post-lining "n" is seen to be consistently 0.011, reflecting a notably smoother condition. Post-lining measurements of the internal diameter of the rehabilitated conduit revealed it to be 10.02 in. (25-45 cm), compared with 11.875 in. (30.46 cm) prior to lining; the in-place liner thickness was .365 in. (.93 cm). The reduced cross-sectional area of the sewer coupled with the added smoothness of the liner increases the capacity of the test section from 1.028 MGD (pre-lined), to 1.312 MGD (post-lined), or some 27 percent. Typically this extremely benficial quality of the polyethylene liner can be anticipated down to approximately a 12-inch (30.5 cm) diameter sewer. It should be noted however that, as the diameter of a conduit increases, the roughness of the pipe wall has a decreasing effect on its flow characteristics.

Insituform Lining - Exhaustive cost comparisons and analyses were performed by Buchart-Horn Consulting Engineers in order to establish for various lines in the Hagerstown system the most economical manner of rehabilitation--conventional sliplining or conduit lining by the "Insituform" procedure. As it turned out, for the sections considered, construction costs for "Insituform" were not only slightly less, but also projected inspection costs and land costs necessary for right-of-way acquisition were significantly less--total costs attributable to the rehabilitation of some 512 feet (154 m) of 8-inch (20 cm) line, 3927 feet (1175 m) of 18-inch (45.7 cm) sewer and 1086 feet (325 m) of 27-inch (68.6 cm) diameter sewer were $359,774.92 for conventional sliplining and $311,883.00 for "Insituform". It should certainly not be inferred from this cost comparison that "Insituform" is consistently more economical than sliplining. There are numerous factors which come into play in determining the ultimate cost of each alternative: (1) Accessibility of the site; (2) Amount and type of restoration required; (3) Number and location of services to be reinstated; (4) Availability of staging areas; (5) Public relations; (6) Inspection costs; (7) Traffic control; (8) Time required for complete repair--this partial list is not intended to be comprehensive. As discussed earlier in this report, all of these variables and more must be weighed in developing the optimal technique. As the collection system work progressed many manhole sections previously specified for other types of repair, were added to the "Insituform" contract.

"Insituform" sewer lining was considered mainly in interceptor or trunk lines, which in most cases were bedded in creviced limestone. According to the SSES, the major defect in the sections repaired was pulled or offset joints, mainly in concrete and vitrified clay pipes; there was also some cracked pipe. Although some of the sewers where "Insituform" was used had large numbers of services (Jonathan Street), the sections studied in this report had minimal service connections in order to add credence to the flowmetering results.

Along Northern Avenue between M.H. 1-3 and M.H. 1-5 was an 18-inch (45.7 cm) vitrified clay interceptor sewer which, according to the SSES report contributed 353,952 GPD (1339 M3/Day) infiltrating clear water to the collection system. The sewer lays in a bituminous pavement and is downstream of the Mack Corporation Pumping Station. Television inspection of the sections revealed numerous offset joints, many with root intrusions; pipe barrels were in relatively good condition. In the past these sections had been chemically sealed with grout, but without lasting positive results. The Hamilton Run interceptor sewer basically is aligned parallel to the surface stream, crossing it in several locations; the line runs along the rear of commercial, residential and some agricultural property with access very poor, and in a high ground water location. "Insituform" test sections assigned along the Hamilton Run interceptor include M.H. 3-2 to M.H. 3-6, M.H. 6-11 to M.H. 6-13, M.H. 6-13 to M.H. 5-1, M.H. 5-1 to M.H. 5-2, M.H. 4-6 to M.H. 4-8, and M.H. 4-9 to M.H. 4-11. All sections are comprised of 18-inch (45.7 cm) diameter concrete pipe, having excessive infiltration and root intrusion problems due to pulled and offset joints; in some locations, root intrusion has reached a degree to which it significantly reduces the sewer capacity. Initially conventional polyethylene sliplining was specified for these stretches; however spatial requirements for the slipliner staging area and insertion, and reinstatement of private services would have necessitated an additional expenditure of $33,531.24 over and above construction and inspection costs in order to gain rights-of-way for access to the various sites. With no excavation required for "Insituform" as well as its remote installation capabilities, this access was not required.

The section of sewer running along Memorial Boulevard below a bituminous pavement and between M.H. 9-4 and M.H. 9-6 was also designated as a test section. This interceptor sewer is a 27-inch (68.6 cm) diameter vitrified clay conduit which runs parallel to and just above a 15-inch (38.1 cm) reinforced concrete underdrain and just to the north of the Marsh Run (tributary to Antietam Creek). During periods of high ground water, this section experienced severe infiltration (312,624 GPD (1182 M3/Day) SSES) due to defective joints as well as cracked and broken pipe. At low ground water levels wastewater being transported by the sewer would exfiltrate from the line and migrate into the underdrain, through which it would be conveyed easterly, to end up polluting Marsh Run.

The final "Insituform" test section selected was a 24-inch (61.0 cm) vitrified clay interceptor between M.H. 22-15 and M.H. 22-14, further west on Memorial Boulevard. It was originally intended to test-and-seal this section with chemical grout; however, a detailed internal investigation and cost-effective analysis demonstrated that sewer lining was warranted due to poor joints and deteriorated pipe. Section infiltration was determined in the SSES to be 28,800 GPD (109 M3/Day).

Both the flow characteristics and the infiltration quantities for the before-and-after "Insituform" sections studied were developed automatically by the American Digital Systems, Inc. of Huntsville, Alabama, in the manner previously described in Section 4 of this report; automatic recording flowmeters were typically installed at the upstream and downstream manholes of each test section, where physically possible. By simultaneously measuring the velocity and depth of flow in a conduit of known cross-sectional dimensions, the quantity of flow can be calculated by the formula:

Quantity = Velocity x Area,

where the velocity = $\frac{1.486}{n} \times S^{0.5} \times R_h^{0.67}$ (Manning Equation)

Thus a direct relationship between the depth of flow in the metered section and the quantity flowing is developed for each site; periodic checks and recalibration of each installation are necessary to ensure accuracy.

There are some weaknesses inherent with this type of flowmetering technique. The equipment in many cases cannot achieve the resolution necessary to accurately establish before-and-after infiltration values; and eighth of an inch (.32 cm.) differential in depth of flow in a larger sewer can mean tens of thousands of gallons per day. There are also sources of errors in the collection system itself: (1) turbulence of flow; (2) upstream lift stations; and (3) irregular pipe cross-sections to name a few. Secondly, unless infiltration metering is performed under very similar precipitation and ground water conditions both before and after rehabilitation, erroneous data may be drawn; such was the case in Hagerstown where the Phase 1 rainfall event was measured at 1.59 inches (4cm) and the Phase 11 precipitation was determined to be 1.02 inches (2.6 cm). This would lead the reviewer to infer that infiltration values would be significantly reduced in the Phase 11 analysis (which in several instances was not the case) due to the smaller rainfall event and the sewer rehabilitation which had taken place. ADS staff explained the increased infiltration in several sections of Phase 11 as being due to the fact that the meters were installed in the rather dry fall of 1980 for Phase 1 and were installed in the wet spring of 1981 for Phase 11, and that the rainfall intensities on each rain day varied; generally Daily Average Flows in metered sections in 1981 were appreciably greater than those of 1980. In Table 4 below all pertinent before-and-after repair flow data is presented by section along with actual costs associated with each test section, so that cost comparisons with other rehabilitation alternatives can be made. Please note that the "Insituform" work in Hagerstown included work specified in the original contract, plus a significant amount of work which was added at a later date. Since the velocity calibration and resultant Manning coefficient calculation test were performed in March and April of 1981, the ADS values for $S^{0.5}/n$ at some sites were only before or after values; that is to say in several instances $S^{0.5}/n$ was determined prior to lining but not after, and in several instances it was measured after lining but not prior to. By using the total battery of data however, representative values of before-and-after "n" coefficients could be calculated as shown in Table 4.

TABLE 4 INSITUFORM FLOWMETERING DATA

SECTION (MH-MH)	LENGTH FEET (M)	DIAMETER AND TYPE INCHES (CM)	THICKNESS OF LINER (MM)	DIAMETER AFTER REPAIR INCHES (CM)	SLOPE OF SECTION %	SERVICE CONNECTIONS	$\frac{S^{0.5}}{n}$ (BEFORE)	$\frac{S^{0.5}}{n}$ (AFTER)	n (BEFORE)	n (AFTER)	INFILTRATION BEFORE GPD (M 3/DAY)	INFILTRATION AFTER GPD (M 3/DAY)	CAPACITY BEFORE MGD (M 3/DAY)	CAPACITY AFTER MGD (M 3/DAY)	COST OF LINING[9]	INFILTRATION ELIMINATED IN G.P.D. (M 3/DAY)	COST PER GPD ELIMINATED
1-3 1-5	638 (195)	18" VC (45.7)		17.00 (43.2)	0.52	1	-------	6.0263	0.0135	0.0119	166,000 (631)	337,000[1] (1280)	4.59 (17,000)	4.39 (16,200)	$52,346	---------- (----------)	$----------
3-2 3-6	377 (115)	18" VC (45.7)		17.00 (43.2)	0.44	0	3.4250	-------	0.0194	-------	120,000 (456)	-------[2] (----)	2.97 (11,000)	----- (--------)	$33,402	---------- (----------)	$----------
4-6 4-8	704 (215)	18" VC (45.7)	9	16.63 (42.2)	0.43	0	3.4553	3.3873	0.0190	0.0194	25,000 (95)	0 (0)	2.98 (11,000)	2.33 (8,600)	$57,728	25,000 (95)	$2.31
4-9 4-11	249 (76)	18" VC (45.7)	6	17.00 (43.2)	0.43	0	3.5414	-------	0.0185	-------	32,000 (122)	2,000[3] (8)	3.06 (11,300)	----- (--------)	$20,418	30,000 (114)	$0.68
5-1 5-2	457 (139)	18" VC (45.7)	9	16.63 (42.2)	0.73	0	4.2223	7.5695	0.0202	0.0113	154,000 (585)	371,000 (1410)	3.57 (13,200)	5.17 (19,100)	$37,476	---------- (----------)	$----------
6-11 6-13	706 (215)	18" VC (45.7)	6	17.00 (43.2)	0.67	0	3.3560	7.8858	0.0135	0.0104	437,760[4] (1663)	0 (0)	5.20 (19,200)	5.62 (20,800)	$63,088	437,760 (1663)	$0.14
9-3 9-6	1085 (331)	27" VC (68.6)	9	26.38 (67.0)	1.17	1	-------	11.5104	0.0135	0.0094	377,424[4] (1434)	-------[5] (----)	19.65 (72,700)	26.88 (99,500)	$104,180	---------- (----------)	$----------
22-14 22-15	272 (83)	24" VC (61.0)	9	23.50 (59.7)	0.42	2	3.6580	5.5381	0.0177	0.0117	93,000[6] (353)	32,000[6] (122)	6.39 (24,400)	9.56 (35,400)	$26,343	61,000 (231)	$0.43
6-13 5-1	836 (255)	18" VC (45.7)	9	16.63 (42.2)	0.73	0	-------	7.8858	0.0135	0.0108	43,200[4] (164)	0 (0)	5.36 (19,800)	5.23 (19,400)	$68,862	43,200 (164)	$1.59
TOTALS AND AVERAGES									0.0165	0.0121[7]						596,960 (2267)	$1.03

NOTE: ALL FLOW DATA COMPILED FROM FIELD DATA GATHERED BY AMERICAN DIGITAL SYSTEMS, HUNTSVILLE, ALABAMA

1. INACCURATE DATA DUE TO MACK PUMP STATION UPSTREAM.
2. FLOWMETERING DATA ERROR.
3. TOTAL INFILTRATION FROM M.H. 4-8 TO 4-12, 13,000 GPD, BUT ONLY 2,000 GPD ASSUMED FROM M.H. 4-9 TO 4-11 (INSITUFORM)
4. DATA FROM BUCHART-HORN SSES; METER INSTALLED TOO LATE TO OBTAIN PRE-LINING INFILTRATION.
5. SITE NOT MONITORED BY ADS.
6. LOW GROUND WATER INFILTRATION USED IN THIS CASE RATHER THAN HIGH GROUND WATER INFILTRATION AS WAS PRESENTED IN REMAINDER OF DATA.
7. ELIMINATE THE OBVIOUSLY HIGH READING OF 0.0194.
8. DISREGARD SECTIONS FROM M.H. 1-3 TO M.H. 1-5, M.H. 5-1 TO M.H. 5-2, M.H. 9-3 TO M.H. 9-6, AND M.H. 3-2 TO M.H. 3-6, IN WHICH DATA IS OBVIOUSLY ERRONEOUS OR IS INCOMPLETE.
9. DOES NOT INCLUDE COST OF OVERPUMPING.

The majority of the flowmetering data supports what one would suspect: (1) sections lined with "Insituform" offer a smoother surface than the original pipe--pre-rehabilitation "n" (average) was 0.0165 while post-rehabilitation "n" (average) was calculated to be 0.0121, an improvement of 27 percent; (2) the infiltration was reduced from a total of 630,960 GPD (2400 M3/Day) for applicable test sections to 34,000 GPD (129 M3/Day), a decrease of some 94.6 percent. Capacity changes of lined sections was a difficult parameter to interpret; in approximately half the sections in which before-and-after capacities were determined, the capacity decreased after lining, with the remainder showing increased capacities. The reasoning behind this rather inconclusive data was primarily due to two factors: (1) the Manning roughness coefficient (n) in the lined sections was much greater than that claimed by the manufacturer in published literature; (2) postlining diameter of the Insituform section has apparently been misrepresented by flow metering consultant. The City is currently in the process of varifing these values.

The Achilles heel of the sewer rehabilitation program is the private service, through which it is estimated that between 30 and 70 percent of I/I enters a sanitary system; until methods are developed to rehabilitate services, the ultimate goal of the sewer rehabilitation program--that of removing all excess inflow and infiltration from the collection system--will never be realized. Such is the case with "Insituform"; in manhole sections having numerous service connections, the ground water which is prohibited from entering the mainline simply migrates toward the deteriorated services where it easily infiltrates to become flow which must be transported to the wastewater plant for treatment.

Cost-Effective Analysis of "Insituform" and Other Rehabilitation Techniques in Different Geologies:

The cost-effective analysis performed over the course of this study was limited to sites and techniques considered; costs noted herein may not be representative of specific locales not studied. To summarize and compare unit costs per gallon of infiltration eliminated daily as presented in previous sections of this report, the following table is presented:

TABLE 5 COST-EFFECTIVENESS OF REHABILITATION TECHNIQUES STUDIED

Technique	Percentage of Infiltration Removed	Cost per GPD of Infiltration Eliminated
Point Repair/ Test-and-Seal	94.7	$0.21
Conventional Sliplining	84.1	$1.85
"Insituform"	94.6	$1.03

* City staff to provide updated results.

The cost value presented in Table 5 for the sliplining alternative may be misleading due to the fact that although the pipe diameter is less, the sliplining project evaluated was of small scale in comparision with the rather imposing scope of the Hagerstown improvements; certainly economies of scale came significantly into play. Buchart-Horn, prior to awarding the Hagerstown sewer lining contract to the "Insituform" installer, performed a cost comparision between the two options on the originaly-designated lining sections; costs included in the analysis were construction, overpumping and traffic control, preliminary cleaning and inspection, inspection and land acquisition. Using infiltration values listed in Table 4 for the selected manhole sections involved, in conjunction with prices developed by Buchart-Horn the following more representative table has been developed.

TABLE 6 COST-EFFECTIVENESS
"INSITUFORM" VS SLIPLINING

MH Section (All 18" Dia.)	Infiltration Eliminated GPD (M^3/Day)	Cost "Insituform" (Proposal)	Sliplining[3]	Cost per GPD of Infiltration Eliminated "Insituform"	Sliplining
4-6 4-8	25,000 (95)	$63,038	$75,670	$2.52	$3.03
4-9 4-11	30,000 (114)	$21,632	$27,933	$0.72	$0.93
6-11 6-13	437,760 (1663)	$64,303	$53,018	$0.15	$0.12

1. Assume both methods eliminate the same quantity of infiltration.

2. Liner imported from England; local source may reduce costs.

3. From Buchart-Horn estimate with five years interest at 8% added.

As can be seen in Table 6, generally convention sliplining was shown to be less cost-efffective than "Insituform" in the sections studied, when considering the additional bypass pumping, investment of land and cost of inspection. The cost differential shown here may be affected by intangibles such as the sociological impacts of traffic pattern disruption and incoveniences associated with a procedure involving excavation; although the "Insituform" manufacturer claims that there is the added advantage of increased hydraulic capacity in a sewer which has been lined with their product, this claim was not borne out by the data collected for this report. It would seem that "Insituform" would have a definite advantage in applications in which space or access is limited or where surface restoration costs are extremely high; every site should be considered individually based upon its own idiosyncrasies and requirements.

According to the data assembled during this study, the combination of point repairs and grouting was the most cost-effective sewer rehabilitation technique used in Hagerstown, all things being equal. However two considerations should be taken into account: (1) generally, point repairs and grouting were performed on small-bore lines, thereby reducing costs from the lined sewers, which were basically large-diameter interceptors; (2) the service life of the sewer sealing material is open to controversy, and assuming that a sewer section might have to be sealed several times over the life of a liner, the cost-effectiveness of the test-and-seal alternative becomes increasingly less meaningful; and (3) point repairs were performed in-house and therefore costs might not be typical.

In many of the sections rehabilitated in the Hagerstown project, the sewer was laid in creviced limestone bedrock; ground water in this type of geology may fluctuate greatly, being directly and rapidly reactive to precipitation events. Following a significant rainfall event, the ground water table may rapidly rise over the crown of the sewer; due to the crevices and solution cavities in the bedrock, however, the ground water level recedes quickly after rainfall stops. This cyclical wet-and-dry atmosphere is not conducive to the test-and-seal repair technique, since the grout material tends to shrink as it dries, thereby allowing infiltration to return to the sanitary sewer; many contractors use such admixtures as inert fine solids (silica flour, diatomaceous earth, bran, sawdust, bentonite or portland cement) or chemicals such as calcium chloride or ethylene glycol (where solids cannot be pumped due to the limiting grain size of the soil or fissure size of the rock) to reduce grout shrinkage--these admixtures change gel times appreciably, and therefore manufacturers should be consulted prior to the use of admixtures. When rock or very coarse soils or backfills are encountered, a flocculant may be used to increase the viscosity of the grout solution, thus reducing the pumping flow rate. The measures described tend to keep the grout close to the sewer joint by creating a blinding effect in the interstitial spaces of the bedding and/or backfill. The acrylamide grout generally depends upon the imperviousness of the backfill surrounding the pipe to provide lateral support needed to create a watertight joint seal.

The hydrogeology of a site has very little effect on the conventional sliplining technique, other than the excavation work involved in staging and termination pits, and the reinstatement of service laterals; considerations presented herein, therefore, are also applicable to point repairs. Ground water must be conveyed out of any excavations, usually be means of a pump to the extent that work may proceed unencumbered. The nature of the geology directly effects the equipment and materials necessary to perform excavations for point repairs, pits and service connections; although most soils and weathered bedrocks may be excavated by conventional machinery, intact bedrock may require blasting with explosives to accomplish excavation. Excavations, especially deep excavations, must be performed in strict accordance with OSHA requirements; the ability of the native soil profile to be stable in trench walls effects excavating techniques, and therefore the cost of the work.

Ground water and earth above any structure located below grade impose static loadings upon that structure; the manner by which a flexible conduit derives strength by utilizing the lateral support provided by the bedding and backfill has been explained previously in this report. The character of the backfill above the conduit is a major determining factor in calculating earth loadings; sand and gravel backfills tend to be of moderate density when compared to the much more dense clay material, and therefore earth loadings in the clay situation may be 40 percent higher than that experienced with the granular backfill. Obviously the higher the ground water level is above the pipe, the greater static hydraulic loading is placed upon the conduit. Pipe for point repairs or for conventional sliplining must be designed to withstand these loadings, with limited deflection in the case of the flexible polyethylene pipe. As the loading increases, the Standard Dimension Ratio (SDR), which represents the outside diameter of the pipe divided by the pipe wall thickness, must be incrementally reduced. Generally, for each decrease in the SDR number of polyethylene pipe, external loading capacities are approximately doubled. As the SDR decreases, the hydraulic capacity also decreases and the unit material cost rises.

"Insituform" also must be custom-designed using thicknesses and materials to withstand anticipated loadings at each site; however, excavation in most cases need not be considered. In cases where the excavation necessary to stage for sliplining, or to perform point repairs for service reinstatements is significant in quantity or degree of difficulty, "Insituform" may be the cost-effective method of sewer rehabilitation; however, each site should be considered individually.

The localized migration of cold ground water through creviced bedrock around the existing sewer may create a heat-sink which in the case of "Insituform" requires additional curing time and temperture to completely affect a total chemical reaction of the resin. It is believed that some of the lined sections studied during the preparation of this report had bubbles in the liner caused by partial cure of the resin. Additional care must be exercised in "Insituform" inversions with high ground water tables to make certain that the static inversion head remains at a level above the ground water sufficient to invert the "Insituform" at a constant rate.

Once installed and cured "Insituform", as well as conventional sliplining and point repairs, remains relatively unaffected by fluctuactions in ground water. Both "Insituform" and sliplining are impermeable when properly installed; however, every effort should be made to prevent the migration of clear water along the annular space between the liner and the original pipe into nearby manholes.

Service Rehabilitation:

"Insituform", as well as some of the larger conventional slipliners and grouters, have done considerable research on the problem of service rehabilitation without the requirement of excavation. In fact in June of 1981, Insituform of North America, in response to a Federal E.P.A. request, submitted a detailed proposal to develop and test a technique for the rehabilitation of house laterals without excavation; apparently the program was deleted from the FEPA program due to lack of funds.

Small-diameter closed-circuit television systems are available and would be required to internally inspect the lateral prior to any lining; these could be introduced into the service through a cleanout or other fitting within the building. All pertinent data would have to be noted and pre-lining tasks outlined, i.e. cleaning, root removal, etc.

With the "Insituform" process there are three (3) alternatives by which laterals could be lined without excavating:

1. Lining from the building toward the main line using a portable pressure inversion unit.
2. Lining from the sewer main toward the building using a remote inversion tube.
3. Lining from either end without inversion, using a drag in method and an inflation tube.

There are many refinements to be made in the process and equipment necessary for these techniques to be feasible, and many more if one or more of these alternatives is to become cost-effective. Each of these alternatives will be studied in more detail.

Portable Pressure Unit - This technique consists of placing a portable water pressure unit over the end of the service or another point of service access either inside or out of the building. The liner liner can pass through the pressure unit and into the lateral by means of a gland and gear assembly. A water supply pump with an adjustable pressure relief valve provides the pressure to invert the liner into the lateral.

A lay-flat recirculating hose will be pulled into the liner much as with conventional inversion to facilitate resin cure. The inversion will be complete when the liner turn-back reaches into the main line as evidenced by closed-circuit television.

Curing of the liner will be accomplished by circulating hot water through the liner. Services may then be reinstated using a remotely-controlled pneumatic cutting device or the "Insitucutter" in conjunction with the television.

Remote Inversion Tube - In this alternative an "Insituform" liner of required dimensions would be preloaded into a high-pressure hose. A tag line would then be floated from the building access point through the service and into the downstream manhole where it will be attached to the "Insituform" liner. Using a television camera/cutter assembly the hose will be positioned at the service to be lined. Two hoses and a tag line would be attached to the rear of the pressure tube. One hose would be used to supply water for inversion and as a suction hose during circulation; the other would be attached to the end of the liner liner to be used as a discharge hose during hot water circulation.

To invert the liner water would be pumped into the pressure hose. creating a positive head sufficient to invert the liner; the tag line would be pulled toward the building by a laborer who- in effect. controls the rate of inversion by providing the majority of the inversion force. Curing in the normal manner would begin when the liner turn-back reaches the access point. After curing and cool-down has been completed, each end of the line will be cut away.

Drag-in Inflation Tube - A resin-impregnated liner would be physically dragged into the service from either end by means of a cable which was floated in or dragged by mechanical methods. The liner would be inflated against the sides of the conduit using a tube installed in the liner during wet-out; a section of lay-flat hose would also be inserted at this time.

A television camera in the sewer main ensures the position of the street-end of the liner. When the liner is in proper position, the inflation liner is filled with water by a pump or using water-main pressure until the liner is positioned securely against the service walls.

Hot water is now circulated through the inflation liner until cure is achieved; after curing and cool-down, the inflation tube is removed and any necessary trimming is performed.

These alternatives appear to have sufficient promise to warrant further attention and study.

"Insituform" Durability and Service Life:

In order to explore the overall successfulness of the "Insituform" product in the North American continent, thirteen representative sites were visited and studied in detail. The information gathered via these inspections has been evaluated and summarized herein.

Generally, the reaction to the repair work was quite positive with concerned parties quite willing to contribute information. In each case studied, the "Insituform" liner virtually eliminated infiltration or exfiltration from the lined section proper; noticeable deterioration of the product from its original installation condition could not be detected. This section of the report summarized the on-site findings for the investigated sections, and interprets the interview data.

Lines investigated ranged in size from 6-inch (15 cm) diameter through 36-inch (91.5 cm) diameter, and suffered from both infiltration and exfiltration as well as structural problems. Weather conditions ran the spectrum from the excessive cold of a Canadian winter to the subtropical Florida summer. Installation approaches varied from standard to remarkably innovative. Here then are the reports compiled by this firm regarding the history of "Insituform."

General Electric Company, Allentown, Pennsylvania

Overview - The installation in Allentown, Pennsylvania, is comprised of 910 lineal feet (277 m) of 6-inch (15 cm) and 303 feet (92 m) of 8-inch (20.3 cm) round concrete pipe transporting chemical waste (chromic acid) under the plant into a holding pond in which the waste received pre-treatment prior to its discharge into the municipal sanitary sewer system; there were no service connections within the repaired sections. Prior to lining, the deteriorated pipe sections were experiencing significant rates of exfiltration which, if left unchecked, could create ground water contamination problems as well as effecting the undermining of structure foundations. Preliminary internal inspection of the conduits revealed several barrel sections to be badly cracked, with some areas broken to the extent that structural failure was imminent.

On-site comments - The plant engineer, assisted by maintenance supervisors, performed flow tests at various points along the sewer in question to establish the severity of the problem; data indicated the waste material tributary to the line was far in excess of the flow measured simultaneously at the sewer outfall near the holding pond. The degree of the problem necessitated further study, and it was decided to internally investigate the pipe by means of closed-circuit television.

The subsequent report revealed numerous serious cracks and structurally-failed pipe; rehabilitation was a definite requirement. Grouting of the line was ruled out because of its ineffectiveness in rehabilitating cracked or broken pipe. Total replacement of the sewers would have necessitated extensive damage to plant floors and furnishings as well as requiring a shutdown of plant operations for an estimated period of three weeks; cost for total replacement would have been in the neighborhood of $100,000.00, not including loss of production during plant shutdown.

It was felt that using the "Insituform" technique would not only eliminate the exfiltration, but would also aid considerably in adding structural integrity to the damaged conduit. The liner could be inserted within the annual two-week company shutdown period, with no disruption to production facilities.

It was determined that three 6-inch (15cm) concrete sections and one 8-inch (20.3 cm) concrete line, 303 feet (92 m) long, should be lined by the use of "Insituform." The sewers varied in depth from a minimum of two-feet (.6 m) to a maximum of 18-feet (5.5 m), the average depth being eight-feet (2.4 m).

Single-ply liners, one-eighth inch (3 mm) in thickness, were inverted into each 6-inch (15 cm) diameter section; multiple-layered liners in these small bore sewers are quite difficult to invert with a static water head. A double liner totally one-quarter inch (6 mm) thick was inserted into the larger sewer, rendering an added factor of safety with respect to structural qualities of the section. Because of the particularly-aggressive environment to which the liner must be exposed, a more inert thermo-setting resin was used in this application.

Total time for the entire project to be completed was eight days. The actual inversion of the liner went quite smoothly, with the only noticeable problem being the added work involved in the preliminary cleaning of each section. This extra cleaning delayed the completion of the project by several days.

Final cost of the installation approximated $60,700.00 with unit prices for the different sized sewers being $40.00 per lineal foot of 6-inch (15 cm) diameter line and $45.00 per lineal foot of 8-inch (20.3 cm) sewer line, including cleaning and internal inspection. Data gathered from preliminary flow-metering was not made available and therefore a cost per unit exfiltration eliminated could not be calculated.

Interviews with the client indicated him to be very satisfied with the work from beginning to end. The installation was performed within the time frame allotted at a significant cost savings over the replacement option. Before-and-after investigations displayed a vast improvement, with no noticeable deterioration over time obvious.

Fairfax County Department of Public Works, Fairfax Virginia

Overview - This project consisted of lining by the "Insituform" technique approximately 4800 lineal feet (1463 m) of 30-inch (76.2 cm) diameter concrete pipe along the Holmes Run; access to parts of the site was a severe problem due to its location in a heavily-wooded area paralleling a stream in which the water level was from 4 to 6 feet (1.2 to 1.8 m) over the invert of the sewer. The sewer section in question was more readily accessible and had offset and pulled joints, cracks in all quadrants, as well as pieces missing from the pipe walls; root intrusion was also noted in areas.

The Department of Public Works, Line Maintenance Division of Fairfax County, Virginia, is responsible for approximately 2400 miles (3862 km) of sewerage collection system; the department is equipped to perform internal inspection, grouting and polyethylene sewer lining tasks, and therefore performs a great deal of sewer rehabilitation "in-house."

On-site comments - The remoteness of this site, in conjunction with very high area water table, contributed to make this an excellent test section for "Insituform" installation innovations and effectiveness. The poor condition of the pipe previously allowed great quantities of infiltration to enter the wastewater flow, resulting in downstream difficulties regarding transportation and treatment.

This project consisted of lining 4810 lineal feet (1466 m) of badly deteriorated 30-inch (76.2 cm) diameter concrete sanitary sewer with no services; much "Insituform" lining had previously been installed in the district collectors, with a total of approxiamately 9000 feet (2743 m) in place (generally in large-bore pipe). The longest section inverted within the study area was 400 lineal feet (122 m), with the shortest being 129 lineal feet (39 m). The structure of the liner consisted of four-three millimeter thicknesses of felt material, covered with the thin polyethylene membrane--the liner walls, prior to inversion, were 12 millimeters, or approximately one-half inch in thickness.

Inversion of the liner material was made in the conventional "Insituform" installation manner, whereby scaffolding was erected at most accessible manholes from which installation was made by using a static head of water; no overpumping of wastewater was required in this instance however.

Cost of the recent work totaled $492,544.00, which reduced to a unit cost of $102.40 per lineal foot, including preparatory an post-lining functions. A cost-benefit analysis of each possible rehabilitation technique viable in this situation was performed by the public works staff, with the "Insituform" method determined to precipitate optimum benefit per unit expenditure--economic, environmental and social factors being considered.

Infiltration was eliminated from the lined pipe by the "Insituform," and structural stability provided by the multiple-thickness liner. Fairfax County Department of Public Works officials are highly satisfied with the performance of the "Insituform" product to date, and indeed are currently in the process of establishing "Insituform" work for the upcoming construction seasons. No deterioration of any of the "Insituform" lined sections has been detected over its life span as of this report. Although they are quick to point out that this product is not a panacea for all sewer problems, the public works staff does consider the installation of "Insituform" cost-effective in numerous situations within their system; they stated that, taking all factors into consideration, the end unit cost of "Insituform" has been no more than that for sliplining, and in most cases has been less.

Potomac Electric Power Company, Washington D.C.

Overview - This project was rather small, consisting of eighty lineal feet (24 m) of 24-inch (61 cm) diameter concrete storm sewer, the invert of which had been completely eaten away in some areas by acid concentrations--mainly sulfuric acid. The line runs beneath railroad tracks, next to the foundation of a structure and in an area where the location of existing utilities is not precisely documented; formerly the site was a coal storage yard.

On-site comments - Visual inspection of the storm sewer by plant personnel established the line to be a serious source of exfiltration, which ultimately would contribute to undermining the building foundation and the railroad bed; the flowline of the conduit had been completely destroyed in some places by concentrated acids, mainly sulfuric acid. The sewer is a 24-inch (61 cm) concrete pipe varying in depth from seven to nine feet (2 to 2.7 m), with one eight-inch (20.3 m) service tap in the section; manholes are located at the extremities of the section to provide access. Since this is a private installation, before-and-after exfiltration values were not documented. The water table in the areas was below the sewer elevation so that ground water infiltration was not a problem at this site.

Plant personnel indicated that it would have been normal procedure to entirely replace the storm sewer with new; however, due to the close proximity of the line to various structures, including railroad tracks and utilities of questionable locations, it was decided that the "Insituform" method would be most expeditious in achieving the desired end in a cost-effective manner. Cost data was not made available by the plant staff; however, the records of the installer showed the job to cost $191.25 per lineal foot, or $15,300.00 totally. The high unit cost for this work may be attributed to the limited amount of sewer to be rehabilitated; the mobilization-demobilization charges associated with this work translate into high unit costs when spread over a small installation.

The liner itself was composed of three, 3-millimeter felt plies overlain by a polyethylene membrane--total liner thickness being nine millimeters. Inversion of the liner was conventional, with one 4-inch (10.2 cm) pump used to bypass the small amount of flow around the section to be repaired. After the liner had completed its curing cycle, the service connection was cut out manually by contractor personnel. Total time for the rehabilitation work was less than twenty-four hours. including the service reinstatement.

Potomac Electric personnel associated with the project were highly satisfied with its success in relieving the exfiltration problem. Visual inspection of the section recently revealed that the liner was essentially in the same condition as when installed in 1979.

Westinghouse Defense and Electronic Systems Center, Baltimore-Washington International Airport

Overview - This situation represents one of the most typical applications of "Insituform" within the private sector; a storm conduit under a plant had joints in such poor condition as to render it susceptible to both infiltration and exfiltration problems. The conduit was lined by means of the "Insituform" technique early in 1980.

On-site comments - Approximately 130 lineal feet (39.6 m) of 21-inch (53.3 cm) diameter reinforced concrete storm drain running almost entirely under this industrial facility had settled differentially to the point where exfiltration and infiltration through the joints had become significant problems. The infiltration contributed such a degree of clear water flow. that the remaining capacity of the sewer was not sufficient to transport the imposed load; hence, surcharging resulted. Commonly associated with this situation are problems with the integrity of the floor and footing systems due to bedding washout.

Plant engineers studied the problem and made the decision that it would be too expensive to reconstruct the sewer under the plant floor--first cost would have been substantial, with the associated loss of productivity providing an added incentive to find an alternative method. Cost studies reinforced the concept of lining with "Insituform".

The storm sewer varies slightly in depth from 6 to 7 feet (1.8 to 2.1 m), and has manholes at either end. with one being just outside the building; groundwater during inversion was beneath the conduit and thus created no problems. There were some lateral connections in the line which. after curing, had to be manually reinstated.

After preliminary cleaning, a three-ply (9 mm total thickness) "Insituform" liner was installed from the manhole exterior to the building in an upstream direction; it was not necessary to damage the plant facilities in any way and production remained unaffected. Cost for the installation was $14,400.00 or $110.77 per lineal foot; here again, due to the shortness of the section, an inordinate amount of cost was attributable to mobilization factors.

Inspection of the liner revealed that the present condition of the material had not deteriorated over time. The client was apparently quite satisfied with the rehabilitation choice.

City of South Daytona, Florida

Overview- This site consisted of the rehabilitation of 2208 lineal feet (673 m) of 15-inch (38 cm) diameter and 3940 lineal feet (1201 m) of 12-inch (30.5 cm) vitrified clay pipe in which pulled and offset joints led to considerable clear water infiltration. The original sewer was installed in 1959 with oakum and hot tar joints, all along paved roadways; line rehabilitation via the "Insituform" process began early in 1980.

The City of South Daytona discharges its wastewater from the collection system into the Daytona Beach, Florida, collection system, through which it is transported to the Daytona Beach Wastewater Plant for treatment. South Daytona is then billed based upon this hydraulic contribution, whether it be sewage or clear water; hence it was to the advantage of South Daytona to minimize the flow by reducing infiltration.

On-site comments - Many of the joints in the original 12-inch (30.5 cm) and 15-inch (38 cm) sewer line had failed since its installation in 1959; staff personnel believe this to result from the theory that the hot tar was applied while the pipe was laying in water. The resulting system was exposed to differential settlement and is therefore a source of considerable clear water entry. Tidal forces compounded the problem by washing granular backfill material into the sewer through broken pipe and bad joints, seriously undermining roadway structures as well as the bedding of the sewer. The lined sections have a total of 112 6-inch (15 cm) service connections, and therefore this site represented a true test of the patented "Insitucutter" method of internally reinstating services.

Pressure sealing with chemical grouts was performed in the past on the lines studied, with limited success; it seemed that continued pipe settlement coupled with grout shrinkage led to a situation in which the infiltration returned after a period of time. Although pressure grouting is an effective technique in reducing infiltration. circumstances at this site were such as to render the method ineffective in the long term. Replacement of the mains was considered; however, due to the unstable nature of the soil a tremendous amount of roadway and surface restoration, along with constant dewatering, would necessarily accompany the replacement work. Thirdly, sliplining with a polyethylene liner was found to be too expensive in this work due to the large number of services and the high restoration costs of digging up each service for reconnection. The most cost-effective alternative was that of "Insituform."

"Insituform" was installed in a conventional manner. on a line-by-line basis during the nights so as to create minimal disturbance. All overpumping of the flow was performed by city forces by means of a temporary forcemain laid on the ground down the middle of the roadway; rerouting of traffic was therefore not necessary. The lining proceeded in a satisfactory manner with only minor technical difficulties causing pre-emption of the work; the majority of the problems experienced were with the use of the cutter in opening services; no excavations were required to reconnect services however. Since the introduction of the process to this continent. many developments have improved the effectiveness and dependability of the cutter over the unit used in Florida. however there remains a long way to go. All affected residents were notified in advance of the impending activities, although no apparent attempts were made to restrict water consumption during lining; service laterals were used as reservoirs until the liner was opened for each--backup of sewage into residences did not become a problem.

The entire 1.2 mile (1.9 km) project. including preliminary inspection and cleaning, lining, and service reinstatement lasted from the first of January until the first of April. During this entire time the ground water was estimated to be at a level nine-feet (2.7 m) above the pipe invert; in the lining process the high water table proved to be no problem. although in many cases special consideration must be given to high ground water. or heat-sink situations. since curing water must be hotter than normal as well as being held at curing temperature longer than normal in order to make up for the heat drawn off by the relatively cool ground water.

Liner material used was two-ply felt totalling 6 millimeters in thickness, both for 12 (30.5 cm) and 15-inch (38 cm) liner; after insertion. curing water was recirculated through the membrane for a minimum of three and a half hours depending upon the length and diameter of the section. as well as the atmosphere in which curing takes place. Generally after cool-down of the recirulating water was completed and the line drained (usually the next morning), service reinstatement was begun; in the majority of cases sanitary service was cut off from consumers for less than twenty-four hours.

City of South Daytona. Public Works staff demonstrated high praise for the "Insituform" process. Prior to lining, daily average flow of the 1.2 mile (1.9 km) section was metered to be 1,038,345 gallons (3,930,100 l); after lining, flow through the same stretch measured 816,462 gallons (3,090,300 l), which reduces to the elimination of 221,883 gallons (839,800 l) of infiltration daily. Using the rate charged to South Daytona for transportation and treatment of sewage of $0.2029 per thousand gallons of flow, the elimination of infiltration converts to a daily cost savings to the City of $45.00, or $16,432 annually. Public Works officials did decide to seal all manholes along the lined section to prevent ground water from migrating to these structures where it could also show up as infiltration.

Total cost for the project was $265,000 (not including bypass or traffic control) or $1.20 per gallon of flow eliminated daily; price breakdown for each size was $31.02 per foot of 12-inch (30.5 cm) liner, and $38.52 per foot of 15-inch (38 cm) liner. Estimated cost for total replacement of the segment was approximately $2 million, not considering the intangible factors such as traffic control, inconveniences, safety hazards, and environmental contingencies. Recent inspection of the liners provided no evidence that the liner properties had changed over the short period of time which it has been in place. The City of South Daytona seemed very satisfied with the procedure and results obtained with "Insituform," and indicated that under defined circumstances the product would be strongly considered again.

NASA Michould Assemby Facility, New Orleans, Louisiana

Overview - In this application, the viability of the "Insituform" product in industrial and commercial conditions is demonstrated; also shown is the ability of custom-designing a system to suit the composition of waste to which it is subjected. This facility produces components for the aeronautics and space program.

On-site comments - Periodic internal inspection of the chemical waste cllection system at the Michoud Facility revealed there to be significant joint and cracked pipe problems in several of the plant lines. Sewers determined to be seriously deteriorated were of vitrified clay material of 15-inch (38 cm) diameter, with bell-and-spigot joints along with a compressive rubber ring. It was suspected by the facility staff and sewer rehabilitation consultants that the high-strength chemical wastes, consisting of very aggressive acid and alkaline solutions as well as organic solvents, had attacked the rubber joints rendering them ineffective. Much of the chemical waste influent to the line were being lost prior to reaching treatment facilities. The concern over the situation was two-fold: (1) chemical wastes escaping the transportation system could contaminate ground water, and (2) infiltration through the poor joints brought with it much of the bedding material upon which the plant was founded--it was learned that floor or footing failures as well as increasing differential pipe settlement could easily result. Some method of pipe repair or replacement was obviously required.

Consideration was given to three corrective actions: (1) total replacement was ruled out due to cost, since much of the defective sewer was under the 8-inch (20.3 cm) reinforced concrete floor slab of the structure; (2) sliplining with a conventional polyethylene liner was eliminated because there was not sufficient area outside the plant to stage this technique--due to a maze of underground utilities, roadways, railroad spurs, etc.; and (3) the "Insituform" method of rehabilitation. To complicate the nature of the project several sets of eighth bends had to be negotiated in order to line some sections.

The lining project was performed in two successive years, the initial section of 794 lineal feet (242 m) of 15-inch (38 cm) clay pipe being rehabilitated in 1979, with the remaining 672 lineal feet (205 m) of 15-inch (38 cm) line lined in 1980; it should be noted that the original work was performed on sewers exterior to the plant, while in the second phase pipes under the factory floor were repaired. The depth of sewers which were lined averaged 9-feet (2.7 m) in the 1979 section and 7-feet (2.1 m) in 1980, with the deepest sewer some 10-feet (3 m) in depth. No service taps were found in 1979 pre-lining inspection; two 12-inch (30.5 cm) service connections were detected in the 1980 work. It was not required to expose by excavation any services for reinstatement.

Analyses of the thermo-setting resin were made in an attempt to verify the composition most inert to the transported material. Installation was then begun using the resistant materials, and in each year was completed, except for cutting out the services, overnight. Anticipated problems with elbows in the lines did not surface, and generally both inversions proceeded without incident. The most recent inversion was performed against the flow from a manhole outside the building, through several interior manholes, and then terminating inside the factory. In each case the client provided standby equipment for overpumping; however, flows encountered did not necessitate its use. The only notable problem encountered by the Contractor was the premature curing of the promoted resin material when left in the sunlight too long; the exposure to heat and ultraviolet rays set off the chemical reaction which resulted in the resin hardening in the mixing containers.

"Insituform" liners used at the Michoud site were 15-inch (38 cm) diameter, one-quarter inch (6 mm) thickness two-ply felt. After installation and curing of the liner, the service taps were internally sawed remotely by the "Insitucutter" instrument.

Cost of the 1979 project (total length 794 feet (242 m)) was $55,521 $5,945 of which was due to "in-house" services--this reduced to a unit cost figure of $69.92 per lineal foot total, or $62.44 per lineal foot actual contracted cost. In 1980, 672 feet (205 m) of 15-inch (38 cm) line was rehabilitated at a total cost of $49,464, $47,485 being contracted cost; the unit value of contract work in 1980 would be $70.66 per foot. These costs include preliminary cleaning work, pre-lining and post-lining television inspection, as well as mobilization and clean up.

Although pre-lining and post-lining infiltration/exfiltration values were not available, the facility staff interviewed was satisfied that their problem had been eliminated. Production at the facility was not hampered, which was also emphasized. Currently the staff has sample coupons of the "Insituform" liner mounted within the sewer lines; at some date in the future, these will be removed and analyzed, to establish the extend of time-related deterioration which has occurred. Visual inspection of the work reveals the liner quality to be excellent, however.

Amerock Corporation, Rockford, Illinois

Overview - Amerock Corporation is major manufacturer of household hardware in this nation. Various trunk sewers of reinforced concrete materials were used under the factory to transport surface water as well as some non-contact waters to a nearby stream. At the outlets of the sewer on the bank of the waterway, it was noticed by Amerock staff that granular material was being deposited; the plant engineering staff concluded that there was a problem with the line under the plant floor, which was allowing the granular bedding upon which the floor and foundation rest to be washed away, raising doubt with its stability. Since much of the sewer runs under the stamping department where heavy machines cause repetitive impact loads on the floor, it was imperative to correct the problem.

On-site comments - The site survey on the Amerock installation was performed approximately fifteen months after placement of the liner. After it became apparent there was a problem with the line, it was decided to internally view the conduit by means of a closed-circuit television system. The inspection revealed very definite factors which had to be considered in the rehabilitation of the reinforced concrete line: (1) the diameter of the conduit changed twice within the defective manhole stretch--at a manhole within the plant the line was 18-inches (45.7 cm) in diameter, then changed to 21-inch (53.5 cm), and finally to 24-inch (61 cm) at the inversion manhole just north of the building; (2) there were two 45-degree horizontal bends in the line located under some stamping machines; (3) the line was very shallow (from 3 to 5-feet (.9 m to 1.5 m) in depth, and therefore to obtain the necessary inversion head the inversion had to take place in the upstream direction from an exterior manhole; and (4) the invert of the pipe had been entirely eaten away--plant officials indicated the the line had been used in the past to transport boiler blow-down flows. These factors combined to make this installation one of the most interesting in this country. Total length of the section is 337 feet (103 m), with 4 lineal feet (1.2 m) being 18-inch (45.7 cm), 142 feet (43 m) of 21-inch (53.3 cm), and 191 feet (58 m) of 24-inch (61 cm) sewer (including two 45-degree bends).

The only two viable options available in this case to rehabilitate the line were those of total replacement and lining. Cost versus benefit comparisons were developed for each alternative, noting both the actual costs of construction as well as those associated with disruption of production. After all parameters were considered, it was decided to impliment the "Insituform" technique.

During the period of time that this job was in planning stages, the liner liners were being fabricated in California, rather than Europe. as had been past practice. Problems with quality control resulted in a liner with numerous pinhole leaks in the polyethylene membrane, thereby giving rise initially to difficulties in obtaining the partial vacuum within the liner necessary to draw the resin into the felt material.

Insertion of the original two-ply, six millimeter thick liner proceeded in an uneventful manner, with the flow being rerouted within the factory; the liner was fabricated to fit the reduction in pipe sizes, having added reinforcement at the reductions. as well as to accomodate the bends. The inversion with water went more easily than anticipated, especially through the bends. However, during the curing operation, the liner split. with the static head being lost. thus creating a situation in which curing was not possible. It was therefore necessary to pull the uncured liner from the sewer, and to start fresh with a new liner. After several weeks, the new liner was inserted, with the only construction-related problem being the difficulty in negotiating the upstream 45-degree bend. The sewer at the bend was exposed and the liner assisted in making the turn; after this was done the inversion and curing phases proceeded without appreciable problems. Roof drain connections were cut out manually after curing by a laborer with a saw crawling through the line.

The installation corrected the foundation problems. and has held up well over its life. Cost for the 337 lineal feet (103 m) of rehabilitation reduced to $37.000.00, or approximately $109.80 per foot. Generally, the finished product was quite acceptable to plant officials.

City of Winnipeg, Canada

Overview - This project was one of the initial North American installations of "Insituform" and was performed by an unlicensed contractor. Sewer rehabilitation in Winnipeg had historically consisted of removal and complete replacement of existing lines until the introduction of the "Insituform" technique. The lines selected for lining were 18 (45.7 cm) and

30-inch (76.2 cm) diameter combined sewers made of cast-in-place concrete, running beneath a roadway in a residential district of the municipality; according to superintendent reports, the ground water level was below the elevation of the sewer. The 18-inch (45.7 cm) sewer was badly cracked with numerous root problems; the depth of this line varied between twelve (3.7 m) and fourteen feet (4.3 m). The large-bore line was cast-in-place concrete approximately twenty-two feet (6.7m) in depth. It was theorized that sulfates in the surrounding clay material attacked the concrete, thus deteriorating it; in some places the conduit had completely collapsed--these areas were rehabilitated using the point-repair technique.

On-site comments - In this sewer project 501 lineal feet (152.7 m) of 18-inch (45.7 cm) diameter and 528 (161 m) of 30-inch (76.2) cm) diameter combined concrete sewers were lined with "Insituform" of six millmeter thickness (two-ply liners); an additional 655 feet (200 m) of 36-inch (91.4 cm) line was originally contemplated, however construction failures mandated deletion of this section from the contract. Average length of the sections lined was 250 feet (76.2 m), with the maximum length approximately 300 lineal feet (91.4 m).

Prior to lining, the sewers were plugged by city forces, with the upstream flow diverted into other interceptors. The city also provided for traffic control whereby only local traffic was allowed, as well as cleaning the lines and the mechanical cutting of root intrusions. The only services encountered were in the 18-inch (45.7 cm) line--these were plugged at the cleanout location, with portable toilets being provided for the residents until services were reinstated.

All lining was performed in a conventional manner in a downstream direction using an inversion tube and scaffolding; unique to this situation however was the extreme cold in which the installation took place--in November of 1978 with the temperature approximately -15°F (-26°C) creating a definite machinery and manpower problem. Municipal staff associated with the project noted two main factors which significantly contributed to the partial unsuccessfulness of the project: (1) the weather conditions, and (2) the apparent inexperience of the workmen suppled by the contractor.

One 258 foot (78.6 m) section of 18-inch (45.7 cm) line was judged to be successful, while a 243 foot (74 m) stretch was determined unacceptable due to a ballooning out of the liner from the conduit wall at both the invert and the crown; it was felt that the non-uniform installation speed caused by hand-feeding the liner into the tube created a fluctuating inversion head condition which allowed air to enter the liner and translated into the above-referenced bubbles. Some 421 feet (128.3 m) of the total of 528 feet (161 m) of 30-inch (76.2 cm) combined sewer was lined satisfactorily with "Insituform"; approximately 57 lineal feet (17.4 m) of the 30-inch (76.2 cm) lining sagged from the crown (attributable to the causes previously described), with some 54 feet (16.5 m) not attempted.

The 18-inch (45.7 cm) diameter section which failed was entirely dug up and replaced with conventional pipe--this is the normal procedure for sewer system rehabilitation within Winnipeg.

After curing, the services on the 18-inch (45.7 cm) line were manually reinstated by a laborer with a saw. The average length of time that any resident was without service was approximately 36 hours, with the maximum loss of service some 48 hours; portable sanitary facilities were provided each resident during this period.

Cost of the overall project was $160,338.28, with 18-inch (45.7 cm) lines being installed at $59.73 per foot, and 30-inch (76.2 cm) liner unit priced at $100.21 per foot; a price of $117.50 per lineal foot was bid for 36-inch (91.4 cm) lining, however this size was never used. These prices were based upon city forces performing preparatory line cleaning and inspection, traffic control, as well as root removal. No before-and-after estimates of infiltration were available so that the effectiveness of the work could be determined.

Generally it could be said that the City of Winnipeg staff remains favorably impressed with the "Insituform" concept as well as the effectiveness of the in-place product; strong consideration would be given to additional lining work provided better product control is exercised and that the end results would be insured. Consensus feeling is that the technology involved with "Insituform" could result in a substantial monetary savings to the city, while at the same time providing an acceptable end product.

Coquelin Run, Chevy Chase Country Club, Hyattsville, Maryland

Overview - The Washington Suburban Sanitary Commission, due to an ever-increasing backlog of pipe replacement requirements within their system, began seriously looking for an effective alternative to the point repair technique of rehabilitating old structurally-defective sewer mains. In 1978, the WSSC initiated the use of "Insituform" as a viable techique in the rehabilitation of their collection system, and over the next three years almost 60,000 feet (18.3 km) of sewer ranging in size from 6 (15.2 cm) to 24-inch (61 cm) diameter was successfully lined with "Insituform".

On-site comments - Approximately 3,272 lineal feet (997 m) of 24-inch (61 cm) diameter WSSC interceptor sewer was lined by the "Insituform" procedure in this project. The sewer was single strength terra cotta pipe with numerous bad joints and cracked pipes; it traverses an exclusive country club, paralleling a creek in many areas, and then flows through a thickly-wooded area. The sewer not only had considerable imminent structural problems, but was exfiltrating to the nearby creek. Logistic and political problems prohibited any use of dig-up and replacement methods; access limitations would not allow for heavy construction equipment to be brought on site. After weighing the alternatives, the WSSC decided to impliment the "Insituform" technique for the area in question. Detailed prior planning was necessary because accessibility to manholes was extremely poor due both to the physical terrain and utility easement restrictions. Negotiations were entered into with the country club to obtain access to specific manholes from which work would be performed.

A total of 3,272 lineal feet (997 m) of interceptor was renovated in a period of three weeks by lining; estimates of conventional replacement construction were at between eight and twelve months in duration. The majority of the lining was completed at night, with disruptions to country club activities and ground minimal, at an estimated cost savings of almost $500,000 over conventional methods. A site inspection of the project area revealed only minimal surface damage, with very little restoration necessary. Through careful study and planning, key insertion manholes were selected from which to invert in each direction; in some cases, to avert disruption of club activities or to accomodate the terrain, lining was performed through more than one manhole section with intermediate manholes being cut out after curing. Ancillary units such as boilers, generators, etc. were generally kept remote from the site, but in some cases were dropped into position using a crane so that wheel tracks would not cross the golf course. Additionally, the contractor at times used golf carts provided by the country club in order to transport pumps from one location to another. The only remnant of the construction activities remaining at the time of inspection was a frame scaffold used on a steep slope in order to level the inversion structure.

One question which is of great concern to anyone contemplating the use of "Insituform" is the extent to which the resin migrates into the service connections and pipe joints. This installation provided a good indication of migration properties of the "Insituform" resin. Traces of resin were found at the ground surface, giving evidence that the material had moved through soil voids a distance of three to four feet--approximately one meter.

The depth of the sewer being lined in this instance varies from approximately twenty feet (6 m) in some areas to three feet (1 m) in others. The majority of the sewer was lined with three-ply liner totalling nine millimeters in thickness; one section under a highway used a four-ply, twelve millimeter liner for a length of approximately 465 lineal feet (142 m). The main reason for the extra thickness was missing pipe crowns throughout this stretch. Visual inspection of the in-place liner revealed absolutely no detectable deterioration over time.

Total cost for the lining work, which included overpumping was $336,847.60, or an average unit cost of $102.94 per lineal foot. Washington Suburban Sanitary Commission was responsible for opening manhole tops so that the inversion shoe could be set in the manhole invert, as well as any point repairs deemed necessary prior to lining; only limited traffic control was required.

Although data is not available referencing the amount of exfiltration eliminated by this project, cursory investigations seem to show the entire problem of the exfiltration, as well as the structural deficiencies, to be corrected. WSSC staff are extremely pleased with the results obtained thus far, to the point where annual maintenance by the "Insituform" method is now budgeted in the maintenance costs for the sanitary sewer system owned by the Commission. As stated in a recent report published by the Washington Suburban Sanitary Commission, "Insituform can certainly be considered the ultimate, best answer for some of those restoration projects, which all sewer agencies encounter and, before Insituform, seemed to defy feasible solution."

Sligo Creek Parkway, Takoma Park, Hyattsville, Maryland

Overview - Here again a site was selected within the jurisdiction of the Washington Suburban Sanitary Commission. It is safe to say that this body was a pioneer in the extensive use of "Insituform" for sewer rehabilitation within this country; the Commission has performed exhaustive research and testing on the product, and has actively participated in the development of various phases of the technology involved. The staff of the WSSC has extensive knowledge regarding the implimentation of this product to rehabilitate sewers.

On-site comments - The Sligo Creek Parkway sanitary line is about 50 years old and runs in a ravine through a wooded nature area along a creek in which rock outcropping is very common; also much of the line was under pavement where restoration costs would be extremely high. In some areas the sewer actually crosses beneath the creek. The facility is a 10-inch (25.4 cm) diameter single strength vitrified clay pipe which is subject to extreme infiltration during periods of high water. and exfiltration when conditions are favorable for this; numerous backups and overflows had occured in this stretch. Common in the lines were offset and pulled joints, as well as severe root intrusion; in some cases the sewer is at a very steep grade which further complicates normal construction methods. Access to the site was a definite problem due to the steep, rocky slopes, the wooded setting, and a narrow roadway in some cases. In past years a sewer line following this route was actually washed out by a hurricane. Reconstruction of the sewer through this stretch was considered, however terrain features, restoration costs, traffic detour problems, and a high water table made the estimated costs and inconveniences of this alternative prohibitive, the reconstruction estimate being at almost three times that for "Insituform." The grouting of pulled or offset joints in areas of fluctuating ground moisture conditions has historically been only moderately successful due to shrinkage problems with the grout. "Insituform" then seemed to provide the most cost-effective manner of alleviating the problem.

This phase of total rehabilitation consisted of lining some 3328 lineal feet (1014 m) of 10-inch (25.4 cm) diameter vitrified clay sanitary sewer, however only 1845 feet (562 m) went to comprise the studied section. The contractor forces performed the preliminary cleaning and internal inspection work; the contractor then had to make a decision whether he felt the sewer was in a condition conducive to the sucess of the process. If further work, such as point repair or root cutting, was deemed necessary prior to the insertion of the "Insituform," WSSC crews were responsible for the completion of this work. Internal televising of the lines did show there to be some sections of the pipe entirely broken out; there were some service taps noted within the study area. however the Sewer Commision chose to expose and reconstruct these services due to the general poor shape of the taps. Overpumping was performed on a section-by-section basis by the contractor- many times using nearby paralleling sewers rather than strictly bypassing around each stretch; typical length for overpumping operations was from 16 to 18 hours. The entire length of this section was lined with a double felt liner of 6 millimeters thickness.

As in the typical installation procedure for "Insituform," all preparaion for the actual lining was performed by a set up crew during daylight hours; when everything was in readiness, a second crew came in to perform the actual insertion, usually in the evening. An interesting sidelight in this project resulted due to the extreme terrain conditions encountered. The Sligo Creek runs down the middle of the ravine. with a narrow roadway on one side of the creek and the sewer on the other. Here again imaginative planning was required to perform the job as expeditiously as possible with minimal damage to the site. Some heavy equipment. such as boilers. generators. recirculation pumps. etc. was stationed remotely from the sanitary sewer in parking areas along the narrow roadway; traffic control was required along the narrow roadway. Scaffolding, liner, and other equipment which had to be set up at the sewer was ferried across the creek on rafts and hand carried to the inversion site. Central manholes were carefully selected from which the lining could be performed in both directions. In several cases intermediate manholes were lined through, and after curing the crown of the liner in these manholes was cut out to allow for future maintenance. As previously stated, the Washington Suburban Sanitary Commission forces, prior to lining, removed existing sewer taps and replaced them with new material. After curing the contractor drilled out the liner material to reopen the service connection. thereby placing the system back on line.

Total cost of the services rendered by the contractor for the 1845 foot (562.4 m) section was $92,106.25, or a unit price of $49.92 per foot of sewer lined; note that this figure includes the preliminary cleaning, inspection, and overpumping charges. Approximate time necessary to line the study section was three to four weeks. Data was not available with respect to the amount of exfiltration or infiltration eliminated from the collection system, but conversations with Commission staff indicate previous problems to be essentially eliminated with no noticeable damage perpetrated recently upon the surrounding park land.

Pre-lining and post-lining video tapes revealed that the root problem within these sections was not corrected satisfactorily prior to lining; these roots were not removed due to client decision, because of the poor condition of the pipe. Roots were compacted by the liner against the top and sides of the pipe; the flow cross-section was visibly decreased in these areas. Recent observation of the linings showed them to be in substantially the same condition which existed immediately after putting them into service. WSSC officials have expressed a great deal of satisfaction with the product over time.

Harbor Springs, Michigan

Overview - The Harbor Springs site consisted of lining approximately 1220 feet (372 m) of 10-inch (25.4 cm) diameter vitrified clay sanitary sewer varying in depth from six (1.8 m) to eight feet (2.4 m); this was located between Lake Michigan and the residences which are served, in an area of very high ground water. The pipe was installed in the 1930's, with sections being approximately two feet (61 cm) in length. Internal investigation of the sewer revealed pulled and offset joints as well as heavy root intrusion; there was no broken pipe detected in the sections previous to lining.

On-site comments - The engineer for this project strongly considered rehabilitation of the segment in question by means of preliminary cleaning and root treatment, followed by sealing the joints with a chemical grout; however detailed analysis revealed lining of the sewer to be the best way to solve the problem in a long-term manner. This application of the "Insituform" technique demonstrates the added precautions which should be taken when a high ground water scenario creates a heat-sink condition; when this situation occurs, additional heat must be provided over a longer period of time during the curing process to compensate for the heat drawn off by the cold ground water, which was two feet (.6 m) above the pipe invert during inversion. Conversations with the installer indicated that the lining has pulled approximately one inch (2.5 cm) away from the crown of the sewer for a short segment of the line--approximately (10) feet (3 m) in length, under a gravel driveway; the installer intended to remove this section in the spring of 1981, and to have it analyzed in an effort to establish the exact cause of the problem. His concern results from his contention that televising of the liner immediately after cure and cool-down showed no irregularities, while an inspection some seven months later revealed the liner sag.

The section studied consisted of 1220 total feet (372 m) of 10-inch (25.4 cm) diameter sewer, the longest stretch being 340 lineal feet (104 m) and the shortest 60 feet (18.3 m); there was a total of fourteen 6-inch (15.2 cm) service taps located over the lined section. A double-layered liner of six millimeter total thickness was installed throughout by conventional methods, although not requiring any bypass pumping. Prior to lining, the sewer was inspected and cleaned of all debris, including roots.

After curing operations were completed, services were reconnected internally with the patented cutter; from the records of the consultant, the average length of time that a residence was without sanitary service was eight hours, with the maximum time being ten hours.

Cost for the lining of the 1220 feet (372 m), including preliminary work, was $43,920 or $36.00 per lineal foot. Figures on the amount of clear water removed from the section were not made available for use in this report, however; even with the sag in the liner, the engineer and municipality seem quite satisfied with the project; the engineer stated that he would certainly consider the use of "Insituform" in other feasible applications. The lining contractor agreed to keep parties concerned appraised of the cause of the sag when this section is tested.

Oliver Street - Cedar Parkway, Chevy Chase, Maryland

Overview - This very old and dignified residential area of Chevy Chase is composed of homes on very small lots, bounding on narrow concrete streets. Generally the sanitary sewer lines were originally installed some seventy years ago, and were located mainly between the curb and the sidewalk, between 8 and

10 feet (2.4 and 3 m) in depth. Over this period of time large trees have developed within the parkway area creating a two-fold problem for the maintenance of these sewer lines: (1) large root systems have in many cases penetrated gaps in the pipe created by deteriorated joints and broken pipe; (2) any conventional replacement of sewers would be extremely expensive due to high restoration costs.

On-site comments - Recurrring sewer problems in this area gave rise to an internal inspection of the lines; notable problems discovered were pulled and offset joints, broken and cracked pipe, along with heavy root intrusion. Various options were considered in an effort to rehabilitate these sewers: (1) removal and replacement would have been too expensive due to high restoration costs, would have disrupted the normal functioning of the neighborhood, and would have taken a long period of time to complete; (2) due to the numbers of services which would have had to be reinstated, with associated excavation and restoration costs, conventional polyethylene sliplining was ruled out--capacity reduction also was a factor in this decision; (3) grouting could not effectively correct broken and cracked pipe.

The contractor under the conditions of this agreement was responsible for the satisfactory completion of all preliminary cleaning, root cutting, and internal inspection, as well as bypass pumping; Washington Suburban Sanitary Commission performed all point repairs necessary for lining to progress.

The test section which was reviewed was 477 lineal feet (145 m) of 8-inch (20.3 cm) diameter, 427 feet (130 m) of 10-inch (25.4 cm) diameter, and 219 feet (67 m) of 12-inch (30.5 cm) diameter terra cotta pipe along Oliver Street. Scaffolding was set up and other preliminary work was performed during the daylight, with the actual inversion performed at night; residents were asked to refrain from the use of water until the services had been internally reinstated by means of the "Insitucutter;" typically residents were without the use of sanitary facilities for betwen 14 and 18 hours, with the maximum service outage 24 hours. Inversion was made in the conventional downstream manner, with flow bypasses around the section being lined. After the inversion of the liner was completed, the contractor typically began circulating the inversion water through a heat exchanger until by means of a pump and back into the liner until the temperature reached 160°F (71° C); at this temperature the catalyzed thermo-setting polyester resin commenced its exothermic chemical reaction, bringing the temperature within the line to approximately 200°F (93°C). After the resin was cured and allowed to cool. the downstream end of the hardened liner was cut off and the services opened internally using a closed-circuit television system in combination with the "Insitcutter" instrument. Nineteen of the twenty services on these stretches were reinstated internally with the "Insitucutter;" operators were unable to position the cutter on one tap due to offset joints, and therefore WSSC had to excavate this lateral for reconnection.

The contracted cost of this work was approximately $50.00 per lineal foot for 8-inch (20.3 cm), $47.00 per foot for 10-inch (25.4 cm) lines, and $59.00 per foot for 12-inch (30.5 cm) sewers. This is in line with a large footage contract entered into between the installer and the Washington Suburban Sanitary Commission.

Follow-up flow studies performed by the WSSC revealed the rehabilitation was effective in eliminating the entrance of infiltration from the sewer mains; however it became apparent that the infiltration was migrating to the manholes and service laterals, where it would enter the system as clear water flow.

Inspection of the lined sections show there to be no apparent deterioration in the quality and effectiveness of the liner over time; the installing agency remains very satisfied with the repair work.

"Insituform" Methods and Problems Specific to Hagerstown:

Field technicians from the Research Consultant were present at a number of the Hagerstown inversions, and developed very detailed notes with respect to techniques employed and problems encountered. Repetitive comments from the inspectors indicated human saety must receive strong attention on a project of this nature. The "Insituform" process generally circulates very hot water under pressure to cure the thermo-setting resin which forms the liner pipe; this hot water generally comes from the boiler unit through a high pressure hose which enters the inverted liner at the top of the inversion tube. As such, during the curing phase of the technique there is extreme danger of scalding should the hose or fittings fail. It is strongly recommended that some type of shroud be constructed at the top of the scaffolding to prevent laborers and/or onlookers from dangers inherent with the curing process; operators should be provided with waterproof suits and gloves, as well as with some type of equipment to protect the head and face areas of the body.

Standard precautions regarding manhole safety procedures must be peracticed religiously. Manhole atmospheres must be checked for toxic or lethal gases; laborers should consistently wear protective headgear, self-contained breathing apparatus or safety harneses in the manholes. Internal combustion engine exhausts must be kept from discharging directly into manholes where men may be working.

Additional development of the "Insitucutter" should be strongly considered, so that the instrument is consistently capable of reinstating services in main lines larger than 15-inches (38.1 cm.) diameter. Presently in sewers of 18-inch (45.7 cm.) diameter and larger, a man equipped with a pneumatic saw is dragged on a sled through the sewer to manually cut the liner away from the services. Should the bypassing system fail with a man in the sewer, water can begin to fill the lined stretch, creating a drowning hazard. Men working in the sewers should have a self-contained breathing apparatus. The remote-controlled mechanical reinstatement of services would eliminate the necessity of exposing a worker to these dangerous conditions. In some cases where the mechanical cutter was used to reinstate services in Hagerstown, it was not successful due to the extreme thickness of the resin plug in some of the services; this can occur when excessive resin is placed into the bag during wet-out.

Some problems have been encontered with the cutter in negotiating 8-inch (20.3 cm) sewers with 1-inch (2.54 cm) and large service protrusions. In some cases these taps had to be exposed and repaired by excavation prior to lining, thereby defeating the advantages of the technique; this problem should be addressed by the manufacturer.

In Hagerstown the majority of the "Insituform" inversion and curing processes are performed during the hours of darkness, and therefore artificial sources of light are necessary to ensure safe working conditions; care must be taken to ensure this lighting is adequate.

Scaffolding used to facilitate the inversion process necessitates some attention to safety; the frame should be founded upon stable material and carefully anchored and leveled. Precautions should be taken to reduce the possiblity of hazards to workers or spectators, i.e. railings around the working levels, a base rail to prevent tools and equipment from dropping off the platform, a waterproof shroud at the working level to guard against the splashing or spilling of hot curing water.

Backboards used to stop an inverting liner at a downstream manhole must be designed for the specific site for which it is to be used. Using a backboard of improper size or strength could allow the liner to break through it, possibly splitting the bag or blocking the downstream lines.

Both in Hagerstown and in other sites visited over the course of this study, there were instances of localized bubbles forming in the flow lines of the sections rehabilitated. It is apparent that this bubble is due to incomplete curing of the resin in the area of the bubble. It is surmised that the thermal stratification of the recirculated curing water (with the warmest water near the crown of the pipe and the coolest at the invert) does not provide for total resin curing in areas of heat-sinks; if extreme care is not exercized during cure and cool-down cycles, a bubble may form in locations of partial curing thereby reducing the available hydraulic cross-section and restricting flow.

The majority of problems seen in this technique are results of poor preventative maintenance programs and insufficient field supervision and preparation by the contractor crews.

Recommended "Insituform" Installation Procedures:

General - There are basically five (5) steps in each "Insituform" lining installation: (1) clean and internally inspect the stretch to be rehabilitated; (2) prepare the resin and impregnate liner; (3) invert the liner; (4) cure the resin; and (5) reinstate services. This section describes the recommended repair process in more detail then previously discussed in this report.

Site Survey and Liner Design - A site survey should be performed for each proposed section to be lined noting such items as: (1) diameter, length, condition, depth and type of sewer; (2) the function of the conduit, whether it be potable water, gas, chemicals, or sewage; (3) the problem associated with the pipe; (4) the amount of cleaning required; (5) the pressures, either internal or external, which will be exerted upon the finished product (soil type and ground water table); (6) any excavations required and the type of restoration associated with each (any shoring required); (7) the availability of a source of water; (8) recommended type of inversion; (9) flow bypassing requirements; (10) optimal liner wet-out procedures and location; (11) recommended type of resin (polyester or epoxy); (12) recommended type and thickness of liner coating; (13) ambient temperature expected; (14) recommended makeup and denier of felt; and (15) a site sketch.

This survey information is used as a basis for calculating the required lining thickness as well as ascertaining the best resin to be utilized. Generally speaking, the loads which will be imposed upon a cured pipe section result from four (4) sources: (1) static soil loads; (2) hydrostatic loads; (3) internal vacuum; and/or (4) internal pressures.

Normally "Insituform" is installed in applications where existing conduit walls can be expected to carry static soil loads; this is due to the fact that the liner is installed without excavation, thereby eliminating initial trenching and bedding settlement factors. In the cases of severely broken or missing sections of pipe, where the erosion of bedding material allows for parent pipe deflections, or shallow lines subjected to strong surface loads, significant flexural or shearing stresses could be imposed upon the liner. Also the liner is exposed to the hydrostatic loads resulting from the ground water.

Formulae utilized to perform thickness designs for "Insituform" applications have been developed from widely accepted pipe equations for specific loadings; these assume adequate lateral support from adjacent soils. Formulae for calculating wall thickness can be obtained from the "Insituform Engineering Guide."

After the size and thickness of the liner has been determined and it becomes time for field work to commence, there are some preliminary steps which should be performed: (1) Install necessary traffic control; (2) Notify residents of impending interuption of water and sewer service; and (3) Installation of bypass system.

Bypass Requirements - Prior to actual installation of the Insituform liner, provisions must be made to overpump the upstream flow around the segment. The actual bypassing set up is of great importance to the success of the lining operation and requires proper planning to assure its adequacy. When planning the overpumping, care must be taken so that placement of plugs, suction line, discharge line and pumps do not interfere with the inversion of the liner.

Considerations in the planning of the bypassing operation include the size of the exising manholes as well as the size and length of the sewer being lined and its wet weather daily average and peak flows. Larger diameter sewers require larger diameter inversion tubes in the inversion manhole, and thus available space for workmen, discharge lines, and suction lines becomes critical. In many cases it is advisable to bypass from one manhole upstream of the inversion manhole to one manhole past the end of the section being lined. Bypass pumping should be scheduled for twenty-four hours continuous duty from the start of the operation, with backup equipment available for periods of maintenance and refueling. The actual length of overpumping will depend on factors such as length and size of line, number of services, normal flow in the line, the physical location of the section, and the relative ease with which the operation proceeds.

In many cases, the bypassing of services would not be required; the reason for this is that the installation of the liner is generally made at night during periods of limited sewer use by the customers. The user is informed well in advance of the installation date that his water service will be turned off for up to twelve hours during installation. Minimal usage of water should not be allowed since this wastewater tends to collect on the outside of the liner at the service tap, and during cutting operations to reconnect the service this water and debris splashes on the camera lens, significantly impairing the view and slowing the reconnection procedure.

If the service cannot be limited or turned off for this amount of time, then bypassing of the service will be required. In many cases this can be accomplished by constructing a small sump between the building and the sewer. The downstream side of the sump is plugged and a pump with appropriate hose is installed. The discharge point for the flow from the sewer service would normally be the same as that for the sewer line being bypassed, unless some provision can be made for an intermediate connection.

Pipe Cleaning and Internal Inspection - Any pipe proposed for lining must be throughly cleaned to permit the internal inspection for conduit cracks or breaks, offset joints, flow restrictions, roots, defective and satisfactory service connections, protrusions or other deficiencies which might preclude or inhibit rehabilitation with "Insituform". Any roots and grease should be removed prior to televising as they might foul the camera lens.

After the initial cleaning, the pipe line should be inspected to determine the extent and location of structural defects. misalignment, protrusions, service connections and points of infiltration, with all data being documented on television report forms and video tapes. Based upon conduit size, condition and loading the line may be internally inspected by closed-circuit television, photographic inspection or manual inspection. Field forms and video tapes are then reviewed in detail to establish the advisability and application of the "Insituform" process, and to ascertain the necessity of any preliminary corrective work to be done on the sewer prior to lining. Also at this time the site should be investigated to establish local soil and loading conditions, physical surface features, ground water levels. flow rates, etc. which would facilitate the design of the liner and aid in defining a plan of action for the installation.

Prior to the actual inversion a much more complete job of line cleaning must be done to remove all debris, grease and roots from the sewer. This final cleaning should be performed as close to the time of inversion as possible in order to ensure that there is no buildup of material from clear water flow sources or upstream manhole sections. Due to the fact that the liner inverts, or reports, into the pipe, there is no relative movement between the surfaces of the liner and the pipe and any object caught between the two becomes encapsulated, and if very large can significantly reduce the liner strength and adversely effect flow characteristics. Equipment useful in the cleaning phase of the lining would include rodding machines. bucket machines, high-velocity hydraulic cleaners or hydraulically-propelled devices.

Prepare Resin and Impregnate Liner - The "Insituform" process generally uses either polyester or epoxy thermo-setting resins. each being quite variable in thixothropy and viscosity. There are three (3) common general-purpose polyester resins used in the "Insituform" process. these being orthophthalic, isophthalic and terephthalic; these resins have marginal differences in chemical resistivity, with the orthophthalic being the least resistant and the terephthalic the most resistant. For higher chemical resistance or high temperature pipes, vinylester resins are generally used. A low reactivity resin is required in the "Insituform" technique, which has a long pot life and a low curing exotherm.

Epoxy resins have slightly better physical properties than polyester because there is a bonding between the epoxy resins and the liner felt fibers; because of their increased physical characteristics and the fact that they bond to many surfaces, thinner sections can be used. Epoxy resins are generally more viscous than polyesters, so a coarser felt substrate must be used to maintain an acceptable wet-out speed; epoxy resins have the majority of their shrinkage during the liquid phase. so that curing shrinkage should not be a problem.

Prior to impregnating the liner with the resin the "Insituform" liner must be cut to the proper length. Care should be taken when determining the length of liner required to serve each application. Consideration must be given to the diameter of line, length of line, and the inversion head proposed to be used. The problems associated with a liner that is too short are apparent. The problems with a liner that is too long are not so apparent but are quite real. A liner that is too long means extra cost for wasted liner and resin and extra manpower to remove the univerted cured portion of the liner. In addition to the above problems. a liner with a long univerted section prevents the hot water in the lay flat hose from being discharged at the end of the liner thereby. potentially adversely affecting the liner cure.

Prior to inserting resin into the liner- each batch should be tested by the installer for quality, exotherm and pot life. Either type of resin may be used general sewer rehabilitation work, but epoxy resins should be specified for applications where shrinkage during curing is not tolerable; resins should be tailored for the medium the liner will be conveying.

Liner impregnation with the resin can be accomplished either at the factory (for nearby jobsites), at a central site near the job, concurrently with inversion in a mobile conveyor unit, or by hand in the case of a very small job.

The same mixing, storage and pumping requirements are in effect for either resin type. Care should be taken in handling the resins and related materials, with strict attention paid to the manaufacturer's warnings and safety procedures; these instructions should be posted at each site. Workers handling resins shall wear rubber gloves and protective safety glasses.

Resins should be stored in accordance with the manufacturer's recommendations, in a cool location but never in direct sunlight; cleaning fluids should not be allowed to mix with resins as this may eliminate or delay full cure. The installer should only use resins with an adequate pot life-12 hours minimum; the installation and wet-out crews should always be aware of the conditions at the repair site, and should adjust the resin to react optimally.

Prior to mixing and catalyzing the resin the contractor should follow these steps:

1. Ensure that the proper quantities of the correct resin and catalyst are on hand.
2. Make sure all employees who will be working with the materials have read and understand all instructions and safety procedures.
3. Check all generators and hydraulic units for fuel.
4. Check ambient temperature and adjust catalyst levels accordingly.
5. Test the operation of all equipment necessary.
6. Check that adequate water supply is available.

7. Ensure that solvents are available in sufficient quantities to clean equipment.
8. Make sure that sufficient lay-flat hose and retention ropes are on hand.
9. Check that adequate and functional safety equipment is available.
10. Resin area shall post "No Smoking" signs.
11. Make sure flow bypasssing system is operable and of adequate capacity.

Once this checklist is completed, the catalyst and the resin should be mixed without delay in accordance with the manufacturer's recommendations using portable drum-type electric mixers which are capable of reaching the bottom of each drum. The accelerator should be mixed into the resin before the catalyst. At this point a marker dye, compatible with the resin used, may be mixed in; this not only verifies the degree of mix, but also helps to ensure that the felt is fully impregnated with the resin.

The next step in the impregnation process is to draw a vacuum on the liner while simultaneously pumping the promoted resin into the felt. The sole functions of the needle felt liner is to retain resin in position until curing is complete. The felt substrate must absorb the resin and hold it in position, as well as providing sufficient strength for the inversion process to take place.

In general, polyester resins require 5 denier polyester needle felt; epoxies use 15 denier generally, but epoxies with fillers make take up to 30 denier felt without excess resin drainage. Polyester felts ranging in thickness from 1/8-inch to 3/4-inch (3 to 18 mm) prior to lining are generally used. as they combine the characteristics of hot strength retention, flame bonding ability and relatively low water absorbancy. The sole function of the polyurethane coating is to provide an air-tight membrane on the liner against which a vacuum can be drawn. to hold the resin in place during cure and to allow the circulation of curing water in the liner. Polyurethane coatings have compatible elestomeric properties and high abrasion resistance, and are relatively resistant to the styrenes driven from the promoted resin during curing; polyurethane coatings are used with polyester resins, and many times. more economical PVC coatings are used with epoxy. The polyurethane is susceptible to fungus and bacteriological attacks and therefore care must be taken during warm weather not to store linings in damp areas.

The first step after the liner has arrived at the site is to visually inspect it for flaws and defects in the coating resulting during manufacturing or delivery. In order to ensure that the entire felt material is saturated with resin, a vacuum pump capable of drawing 20 CFM (1.85 M^3/Min) at 25 inches (63.5 cm) of mercury vacuum is required. A suction pad of 1-1/2-inch (3.8 cm) diameter connected to the pump suction hose should be placed over an area of the liner where a hole has been cut in the coating; the underlying felt should not be cut. As the resin approaches the vacuum pad, remove the pad and patch the hole with a tuftane patch; do not vacuum more than 60 feet (18.3 m) at a time for maximum efficiency. The vacuum pad should be relocated at 60-foot (18.3 m) intervals down the liner, with the final vacuum point at the very end of the liner. Trouble in maintaining a good vacuum may indicate a damaged liner or poor end sealing (check for leakage by ear), or a problem with the pump (check by plugging vacuum line). The most likely site of liner damage is along the folds; extreme care should be taken when handling the liner.

As the vacuum pump is operating, the resin is being pumped by a hydraulic transfer pump into the leading end of the lining in the case of concurrent wet-out/inversion systems, or into the trailing end of the lining through a vent tube in the case of a pre-inversion wet-out system. Initially only sufficient resin to form a seal over the end of the liner is inserted. When a full vacuum (5-8 P.S.I.) is achieved the remainder of the resin is pumped into the liner and it is run through a system of squeeze rollers adjusted such that the gap is equal to twice the norminal lining thickness plus 3/32-inch (2 mm) to obtain saturation. The volume of resin used should be equal to 110 to 115 percent of the volume of felt in the liner. The wet-out process proceeds at a speed dependent upon the felt density, the resin viscosity and the temperature; a speed shall be maintained to preclude the development of any dry areas behind the rollers, as evidenced by the dye.

Any excess resin may be drained into a container. Should insufficient resin be pumped into the liner to fill the felt, additional promoted resin can be pumped in through a tube taking care to keep the liner surface clean. The liner cut shall be closed by hand stitching at 5 stitches per inch (2 stitches per cm.) using four-fold polyester thread doubled; patch over the stitches using tuftane.

The saturated liner must now be kept cool at or below 40°F (4°C) and out of direct sunlight until the inversion process commences.

Site Preparation - Proceeding concurrently with the liner wet-out is the construction of the inversion platform: this generally commences directly after internal inspection of the line has been completed and prior to final line cleaning.

Two types of scaffolding are used throughout the world. The first type is used primarily in this country, and is comprised of a steel inversion scaffolding centered over the inversion structure (manhole); the second system employs a scaffolding adjacent to the manhole but with the drop-tube attachment ring cantilevered over the center of the manhole.

The "Insituform" contractor in Hagerstown utilized either of two types of static water column inversion on this project: (1) top inversion; and (2) bottom inversion; both were used in conjuction with scaffolding centered over the inversion manhole. In the top inversion method, the lining itself is pre-inverted and clamped to the inversion ring at the working level of the inversion platform, with the liner retaining the vertical section of the water column. The inverted turnback of the liner is then manually positioned in the sewer to be lined. This alternative was used primarily in limited access conditions, such as where the inversion elbow cannot be fitted through the manhole rim. Things to be considered prior to selecting the top inversion option of lining are: (1) the added cost of excessive turnback material; (2) the additional problems associated with wetting-out phase; (3) the drop tube is a weak link in the pressure system which may act to reduce the maximum static water head available for inversion and curing; and (4) hold back rope may sometimes cut through the lining where it enters the sewer.

Bottom inversion is the more conventional manner of "Insitufom" installation. A flexible drop tube is hung from the working level of the scaffolding into the inversion manhole where it is attached at the bottom to an inversion elbow. In this method, the liner goes through the drop tube and is folded back and securely clamped to an inversion elbow which is aligned in the manhole with the sewer to be lined. In both the top and bottom inversion techniques, it is imperative that the liner be firmly attached to the inversion ring or elbow. If the liner comes free of the ring or elbow during inversion, the static water head will be lost and the entire liner would have to be retrieved, and if undamaged, reattached to the platform; if the seal is lost during curing, the entire inversion process must be restarted, generally with a new liner. Bottom inversion usually results in less cost than top since less liner material is required. Other advantages to the bottom inversion are: (1) easier liner wet-out; (2) more positive control of inversion starting conditions; (3) no weak links in the drop tube; and (4) no hold-back rope friction in critical areas.

Applications in which the elbow will not fit into the manhole or where access problems or pipe shape preclude elbow/drop tube removal after curing mandate the use of the top inversion procedure; there was one top inversion performed in Hagerstown.

The inversion platform consists of construction-type sectional scaffolding erected as previously described. Care should be exercized when founding the base of the platform to ensure that it is both stable and level; the base should not be shimmed using small blocks or bricks as these may easily be dislodged during construction activities. All scaffold connections and supports should be tight and secure; the entire inversion platform should be constructed in strict compliance with current OSHA standards and requirements regarding construction scaffolding. A suitable baseboard must be installed around the working level platform to protect against falling tools. etc; also a waterproof shroud should be fabricated on the top of the platform to protect against hot water leaks. Any personnel working with the inversion and curing phases of the lining should accordingly be protected with hard hats. safety glasses and shoes. gloves and waterproof clothing.

During inversion the maximum stress on the lining should never exceed 500 PSI (35 kg/sq.cm.); this value should be reduced to 250 PSI (17.5 kg/sq. cm.) during cure. The pressure head is equal to the height of the water column plus the total pipe fall; the inversion head depends upon the pipe diameter and length. the lining thickness. the number and position of bends, ground water and inflow heads to be resisted, the presence of lateral taps which must be made visible. Generally liners require a minimum hoop stress of 100 PSI (9 kg/sq. cm.) to expand them to design size and to invert the liner. Formulae for calculating the inversion heads are as follows:

$$\text{Min. Head (ft.)} = \frac{465 \times \text{Thickness (inches)}}{\text{Pipe Dia. (inches)}}$$

$$\text{Min. Head (m.)} = \frac{170 \times \text{Thicknes (cm)}}{\text{Pipe Dia. (cm.)}}$$

After the inversion platform is in place. the inversion elbow should be hung from the reinforced polyester drop tube and adjusted using the top screw adjustment system so that its center is one-quarter of the pipe diameter above the centerline of the pipe.

Prior to initiating the inversion process, an end stop should be constructed in the section manhole at the termination point of the run in order to ensure that the "Insituform" liner does not invert entirely through said manhole. Every precaution must be taken to provide an end stop which will perform as designed, because failure of this device has in many cases been responsible for failure of the inversion process.

Now after overpumping operations have been started and after provisions for inversion/curing water supply, metering and control are in place, the actual "Insituform" inversion is begun.

Inversion - The "Insituform" liner impregnated with catalyzed resin is now introduced into the drop tube until it clears the inversion elbow. The lining is turned back and tightly clamped to the elbow using two (2) stainless steel bands optimally; this may be done in the manhole or at ground level, whichever is most convenient.

The inversion crew should then reposition the steel elbow in the manhole and put one-half of the calculated inversion head into the drop tube; a block should then be placed behind the elbow to reduce tension on the clamping bands during inversion.

For each thousand pounds (454 kg) of inversion water required, two cubic centimeters each of lubricating powder and effervescent powder mixed with one liter of water is added to act as a lubricant; half the calculated quantity should be emptied into the liner at the initiation of inversion, with the remainder periodically applied to the liner as it enters the drop tube.

The calculated inversion head should be maintained throughout the process by a workman operating a control value at the top of the inversion platform; should be encountered which interrupt the liner progress, the head could be increased to the maximum allowable values previously stated. A pulsing pressure applied to the sides or water level in the drop tube can many times be used to force the liner into movement.

The liner is physically restrained from movement into the sewer until the proper water level is achieved in the inversion tube; when this point is reached, the liner is allowed to report into the conduit to be lined at a rate slow enough to ensure that the static inversion head be maintained in the drop tube. A thermocouple with leads to the surface should be placed between the liner and the pipe as it inverts for future use in the curing cycle. During the entire process the liner should be kept cool and out of direct sunlight.

The liner is allowed to invert at a controlled rate until the end is within 10 feet (3 m) of the top of the inversion tube (the inversion is now approximately one-half complete). A heavy hemp hold-back rope is now attached to the end of the liner by means of wire and tape; simultaneously a high-pressure lay-flat recirculation hose with properly sized and spaced orifices along its length is secured to the end of the liner. These connections should be thoroughly checked as a failure most likely would produce an unsalvageable inversion.

The hold-back rope should next be wrapped around a capstan above the working platform to facilitate a means of restraining the liner as it passes the half-way point; should the liner be allowed to report out unimpeded at this point. it may be very difficult to maintain a constant inversion head.

Should the inversion head be lost and air be allowed to enter the liner. it will be entrapped by the water in high spots in the line. creating localized areas where curing can be very difficult.

As the liner approaches the termination structure, a second thermocouple should be installed between the liner and the sewer in order to monitor resin temperatures during the curing and cool-down cycles. When the inversion is completed, the hold-back rope should be tied around the inversion platform capstan so that the uncured liner is held firmly in position by the backstop and the rope. The liner should be allowed to enter the termination manhole some 6-15 inches (15-38 cm) so that the liner may expand and cause a flared end at the sewer-wall intersection; this to some degree counteracts some of the problems associated with liner shrinkage during cure, i.e. the migration of infiltration along the annulus and into the manhole.

Curing - The promoted thermo-setting resin impregnated in the liner felt is now in position for curing; generally this is accomplished using heated water, although hot air and steam have been used. The mobile boiler unit is now stationed at the site; this is comprised of a heat exchanger, boiler and recirculation pump. along with an electric generator. flexible high-pressure suction and discharge hoses, in-line air relief valves, control valves, flow meters, pressure gauges, thermometers, fittings and ancillaries.

The flexible suction line should be securely connected from the inversion tube to the suction side of the recirculation pump; after purging air from the system, a second high-pressure hose should connect the lay-flat hose with the heat exchanger outlet fitting. The heat exchanger unit should also be connected through a meter and value to a nearby source of water. Since very hot water under high pressure is to be recirculated for this curing process, all connections should be double checked for integrity and all safety precautions per OSHA recommendations exercised. Prior to starting any equipment. standard preventative maintenance procedures should performed, such as fuel and lubricant checks, battery checks, electrical connections and control checks, etc.

The system should first be pressurized by opening the main water inlet valve; after the air is purged from the system. the recirculation pump should be energized and the circulation of flow checked. When all air is out of pressure side of the pump, the discharge line should be connected to the lay-flat hose and the boiler fired up; the pressure gauge should read approximately 10 p.s.i. minimally, with the optimum range between 18 and 20 P.S.I. Note that even though the lay-flat hose is under pressure, flow may not be traveling through the system; the hose may be kinked. Due to different characteristics of various pumping systems, each pump should be individually calibrated to eastablish the flow-pressure relationship. Checks should be made to ensure that the logistics of each site provide sufficient suction head to allow proper pump operation.

Water is now heated at a controlled rate above the desired curing temperature as determined by the type of resin and catalyst used in the process (rate of increase not to exceed 1° C per minute); water temperature should be maintained during the cure period at between 150° F (65.5° C) and 200° F (93.3° C) as measured at the heat source return line and the upstream and downstream thermocouples. The cure period shall be of a duration as recommended by the resin manufacturer; heat exchanger cycling and water recirculation should continue to maintain the temperature. Generally speaking, epoxy resins must have at least three (3) hours at a temperature of 176° F (80° C) before gellation occurs and a very short post cure period; polyesther resins react almost immediately at a lower temperature, but must be maintained at the cure temperature for an additional period of time. The initial cure shall be considered complete when the thermocouples indicate that a reaction exotherm has occured, thereby increasing the measured temperature. A post-cure phase of appropriate time and temperature ensures total cure of the material and the optimal liner characteristics associated with total cure.

Prior to reducing the static head in the inversion standpipe, the temperature of the liner should be reduced to a temperature below 100° F (38° C). To do this, a small hole of 1 to 1-1/2 inches (2.5 to 3.8 cm) in diameter can be pierced in the remote end of liner; as the hot water drains from the hole, cool water should be introduced at the inversion tube to maintain the inversion head (the recirculating pumps should operate continously). The purpose of controlling the speed of cool-down is to prevent the material from experiencing a thermal shock as well as to control shrinkage tendencies. No one should be allowed in manholes directly downstream of the lined section until this 100° F (38° C) temperature is reached.

When the 100° F (38° C) temperature is reached, the backboard may be removed and the static head released by cutting off the turn-back section of the cured liner in the manhole away from the inversion manhole; the release rate should be controlled so that a vacuum will not develop in the section which could damage the "Insituform". At this time both ends of the cured liner may be trimmed within approximately one-quarter inch (.6 cm) of the manhole wall using a small-diameter, pneumatically-operated, right-angle power saw.

Concurrently with the end trimming operations, the crew should carefully dismantle and store the water recirculation system, inversion tube and elbow assembly, and the inversion platform; all water should be purged from the system prior to storage. The bypass pumping system should then be removed assuming flows are small enough to allow for service reinstatement; should this not be the case, bypassing should be continued until all laterals are reconnected. The site should be cleaned up and restored to that condition specified by the client.

After the liner has been allowed to cool down to the ambient temperature and shrinkage of the resin is complete, the annular space between the "Insituform" and the original pipe at the interior manhole wall should be sealed using a mixture of resin and sand. This step is very important as it ensures that ground water will not migrate along the annulus to enter the sanitary system at a terminal manhole. Strong consideration should be given to sealing manholes in the area of the lining repair so that migrating ground water does not enter the system through manhole walls or benches; lateral rehabilitation should also be considered.

The finished "Insiturform" liner should now be continuous over the entire length of inversion, free from foreign inclusions, dry spots pinholes and delamination; any defects noted during final inspection should be repaired to the satisfaction of the client prior to performinq anv final tests on the section. Final hydrostatic pressure tests on the cured liner are basically performed by measuring any water loss in the inversion tube after curing is complete.

Service Reinstatement- After the "Insituform" has cured in place, the contractor should reconnect the existing active service connections as desiqnated by the client; prior to initiating this operation, the contractor should review preliminary internal inspection tapes to familiarize himself with possible troublesome locations and to ensure that all repairs which were specified were actually performed.

This initial step in this phase of the process is comprised of locating the service vehicle and remote winch adjacent to terminal structures, exercizing all manhole safety procedures prior to entry. A tag-line for the camera/cutter assembly is then strung through the lined section by floating, parachuting or by using a hydraulic sewer cleaner. This cable is attached to the camera/cutter assembly, usually in the upstream manhole such that the assembly is dragged through the sewer in the direction of flow. The camera is reversed such that it views the "Insitucutter" so as to position it at each service; due to the fact that the camera is moving backwards in the conduit such that the sewer in direction of movement cannot be seen, great care must be used in moving the equipment through the line so that it does not get stuck at protruding services, offset joints or broken pipes.

Before the camera/cutter is pulled in tandem into the pipe, the operation of each unit should be checked and appropriate adjustments made. As the camera/cutter unit is pulled through the sewer, the pre-lining internal inspection record is used along with the apearance of the liner itself on the closed-circuit monitor, to position the "Insitucutter" at the service; the tap opening appears on the screen as a convex indentation on the pipe wall.

In sections with numerous service taps, the cutter operator should simply drill a hole in the invert of each service line to allow any clear water which has infiltrated the service to drain into the main, as well as to allow the resident minimal service until the total service plug is cut out. Now the "Insitucutter" is used to cut out the liner material which covers each service opening; care should be taken when drilling not to splash water onto the camera lens as this would severely limit visibility.

Services are cut using the closed-circuit picture along with the distinctive sound levels associated with the drill on various materials encountered; the drill should generally be operated along the vertical axis of the service and then along the horizontal axis in order to define the limits of the lateral. The drill is then operated around the circumference of the service to remove all of the lining material; a basket should be placed in the flow line of the downstream manhole to prevent this service material from being transported into downstream sections of sewer.

After all services in the section have been reinstated, the line should be televised and recorded on video tape to document the final condition of the section; this tape should be presented to the client for his records. The residents should be notified that the sewer has been returned to service, and a final site cleanup performed. The finished product should then guaranteed per the requirements of the client.